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ANL-10/31

YALINA-Booster Subcritical Assembly Pulsed-Neutron Experiments: Detector Dead Time and Spatial Corrections

Nuclear Engineering Division

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by
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Abstract

In almost every detector counting system, a minimal dead time is required to record two successive events as two separated pulses. Due to the random nature of neutron interactions in the subcritical assembly, there is always some probability that a true neutron event will not be recorded because it occurs too close to the preceding event. These losses may become rather severe for counting systems with high counting rates, and should be corrected before any utilization of the experimental data.

This report examines the dead time effects for the pulsed neutron experiments of the YALINA-Booster subcritical assembly. The nonparalyzable model is utilized to correct the experimental data due to dead time. Overall, the reactivity values are increased by 0.19$ and 0.32$ after the spatial corrections for the YALINA-Booster 36% and 21% configurations respectively. The differences of the reactivities obtained with He-3 long or short detectors at the same detector channel diminish after the dead time corrections of the experimental data for the 36% YALINA-Booster configuration. In addition, better agreements between reactivities obtained from different experimental data sets are also observed after the dead time corrections for the 21% YALINA-Booster configuration.

YALINA-Booster Subcritical Assembly Pulsed-Neutron Experiments: Detector Dead Time and Spatial Corrections

1. Introduction

As shown in the ANL-10/22 report [1], for many of the pulsed neutron experiments performed in the YALINA-Booster subcritical assembly, the reactivities obtained from the area-ratio method depend not only on the spatial locations of the neutron detectors in the subcritical assembly, but also on the type of the utilized neutron detectors. In almost every detector counting system, a small time interval is required to record an event. The minimum time to record two successive events as two separated pulses are called "dead time" of the counting system. The characteristics of the detector and/or the counting system determine this dead time [2]. Due to the random nature of neutron interactions in the subcritical assembly, there is always some probability that a true neutron event will be missed because it occurs too close to the preceding event. These losses may become rather severe for counting systems with high counting rates, i.e., long He-3 detectors, and should be corrected before any utilization of the experimental data.

This report examines this issue for the pulsed neutron experiments of the YALINA-Booster subcritical assembly. The experimental data are corrected for the dead time then the spatial correction factors are applied [1]. The obtained results can be used to compare with analytical results [3].

2. Detector Counting System Models

Typically, there are two ways of modeling the dead time behavior of the counting systems (neutron detector and pulse counter): paralyzable and nonparalyzable systems. Although these models are ideal, one or the other often adequately resembles the response of a real counting rate. The diagram in Figure 1 compares the differences between these two different models. For system to be nonparalyzable, as shown in Figure 1, "a fixed dead time τ is assumed to follow each event that occurs during the active period of the pulse."[2] The events that occur during the dead period of the counting system will be not recorded and will be also assumed to have no effect on the behavior of the counting system. For paralyzable system, dead time is also assumed to follow each true event that occurs during the active period of the pulse. The other events that occur during the dead period will also not be recorded as counts. However, the dead time of the counting system are assumed to be extended by another period τ following the lost event. In actual experiments, the detailed behavior of dead time losses of the counting system is often dependent on the physical processes and the pulse processing in the recording electronics.

To examine the data losses in a specific model, if we let *n* represent the true event rate, *m* the counted rate, and τ the system dead time. For a nonparalyzable model, the fraction of all the time that a detector is dead is simply $m\tau$. Thus, the true event lost during the dead time is $nm\tau$, and the true event rate can be calculated as:

$$n = \frac{m}{1 - m\tau}. \tag{1}$$

For a paralyzable model, considering the distribution of intervals that random events occurring at an average rate *n* is:

$$P(t)dt = ne^{-nt}dt, \tag{2}$$

the probability that two events occur larger than τ can then be obtained as:

$$P(\tau) = \int_{\tau}^{\infty} P(t)dt = e^{-n\tau}, \tag{3}$$

and

$$m = nP(\tau) = ne^{-n\tau}. \tag{4}$$

Based on the above calculations, at lower counting rates, these two models give almost the same dead time corrections. When the true event rate is high, for nonparalyzable system, the recorded event *m* reaches an asymptotic limit about $1/\tau$; however, for the paralyzable system, the number of recorded events goes through a maximum $1/(\tau e)$ at true counting rate $n=1/\tau$, and then decreases with even higher *n*.

3. Dead Time Corrections of the Pulsed-Neutron Experimental Data

In the YALINA-booster pulsed neutron experiment, the nonparalyzable model is assumed to describe the neutron counting system. The fixed dead time is estimated to be 3.4 μs for the counting system with He-3 detectors. Thus, the maximum counting rates of events that could be obtained in the experiment is estimated to be 2.9×10^5 counts/s.

Based on Equation (1), the reactivity values obtained from the pulsed-neutron experiment data after the dead time corrections for the 36% YALINA-booster configuration are plotted in Figure 2, compared with the reactivities without dead time corrections. Without dead time corrections, the long He-3 detectors always gave slightly smaller reactivity values than short He-3 detectors as shown in Figure 2. This difference is clearly diminished after the dead time corrections. Also, Table I lists the reactivity values and the prompt decay constants with and without the dead time corrections for the 36% YALINA-booster configuration.

Overall, the value of the average reactivity increases by 0.18$ after the dead time corrections. For all the short He-3 detectors, the corrections are all < 0.1$. However, for long detectors at EC1B, EC2B and EC3B channels, the reactivity values after the dead time corrections are increased by 0.35$, 0.28 $ and 0.08$, respectively. At EC5T channel, the reactivity value from the long He-3 detector increased by 0.64$ after the dead time corrections. For long He-3 detectors at EC6T, EC7T, EC8R and EC9R, the reactivity values are also increased by 0.47$, 0.35$, 0.16$ and 0.05$, respectively after the corrections. Additionally, on the average, the dead time corrections also led to 0.3$ increase of the reactivity value at the MC5 channel for the long He-3 detectors. The average prompt decay constant changes by ~1% after the dead time corrections as shown in Table I.

The reactivity values with and without the dead time corrections for the 21% YALINA-booster configuration are listed in Table II, for the long and the short He-3 detectors. The eighth column gives the differences between the corrected and the uncorrected reactivity values and the last column gives the maximum detector counting rate (*m*) for each reactivity measurements. Generally, larger dead time corrections are often associated with higher counting rates, which indicate more neutrons are lost due to the detector system dead time.

Figure 4 compares the reactivity values before and after the spatial corrections for the pulsed neutron experiments performed in December 3, 2009. The dead time corrections lead to a maximum correction of 0.9$ for the reactivity values measured in the EC5T channel using the long He-3 detectors. The corrections at EC1B, EC2B, EC3B, EC6T, and EC7T are 0.43$, 0.24$, 0.11$, 0.54$, and 0.38$, respectively. The corrections for EC8R and EC9R detector channels in the reflector zone are relatively small, and are about 0.16$ and 0.05$ respectively.

Figures 6 to 10 compare the reactivity values obtained before or after the dead time corrections of the pulsed-neutron experiments performed during the period of December, 3, 2009 to March 29, 2010. In particular, in Figures 6 to 10, the reactivity values obtained at each channel in December 3, 2009 after the dead time corrections are plotted as a reference for comparison with later experimental data. In those figures, better agreements of the later experimental data with the reference data are often found after applying the dead time corrections.

4. Summary

The nonparalyzable model has been successfully utilized to correct the pulsed-neutron experimental data in the 36% and 21% YALINA-booster configurations. As shown in Table III, the differences between the reactivity values obtained with the long He-3 detectors and the short He-3 detectors in the 36% configuration have been significantly reduced. For the 21% configuration, the differences at detector channel EC9R, and EC3B also have been decreased. However, about 3$ differences exist at channel EC1B and EC2B.

The spatial correction factors are also applied on the reactivity values with detector dead time corrections at each detector channel, as shown in Table III, Figure 3, and

Figure 5, for the 36% and 21% YALINA-Booster configurations. Originally, with no dead time corrections, the reactivities after the spatial corrections are -4.34$ and -6.17$ for the 36% and 21% configurations, respectively. The reactivity values with the dead time corrections are slightly increased, i.e., -4.53$ and -6.49$ for both configurations respectively.

Acknowledgement

This work has been supported by the Office of Global Nuclear Material Threat Reduction U.S. Department of Energy Under Contract DE-AC02-06CH11357.

References

[1] Y. Cao and Y. Gohar, "YALINA-Booster Subcritical Assembly Pulsed-Neutron Experiments: Data Processing and Spatial Corrections," Argonne National Laboratory, ANL-10/22 (2010).

[2] G. F. Knoll, *Radiation Detection and Measurement*, 3rd edition, John Wiley & Sons, Inc (2000).

[3] A. Talamo, Y. Gohar and C. Rabiti, "Monte Carlo Modeling and Analyses of YALINA-Booster Subcritical Assembly Part II: Pulsed Neutron Source," Argonne National Laboratory, ANL-08/33 (2008).

Table I. Pulsed Neutron Experimental data with and without detector dead time corrections for the YALINA configuration with the 36%enriched uranium fuel rods in fast zone and 1185 EK-10 fuel rods in thermal zone

Batch	Det.	ρ	Δρ	α	Δα	ρ_c	Δρ_c	α_c	Δα_c
0.1	EC5T_S	-4.67	0.02	-671.9	2.5	-4.72	0.02	-673.6	2.5
0.1	EC6T_S	-3.93	0.01	-659.7	2.1	-3.97	0.01	-662.0	2.1
0.1	MC5_L	-3.86	0.01	-673.3	0.8	-4.05	0.01	-687.4	0.8
0.2	EC7T_S	-4.02	0.02	-659.1	1.8	-4.05	0.02	-661.0	1.8
0.2	EC8R_S	-3.81	0.02	-649.5	5.0	-3.83	0.02	-650.1	5.0
0.2	MC5_L	-3.81	0.01	-671.2	0.8	-4.03	0.01	-687.1	0.8
0.3	EC7T_S	-4.00	0.01	-664.5	1.5	-4.07	0.01	-669.1	1.5
0.3	EC8R_S	-3.90	0.02	-641.2	4.3	-3.93	0.02	-642.9	4.3
0.3	MC5_L	-4.29	0.00	-670.2	0.5	-4.96	0.00	-711.1	0.5
0.4	EC5T_S	-4.77	0.01	-672.7	1.5	-4.92	0.01	-677.3	1.5
0.4	EC6T_S	-4.09	0.01	-662.3	1.3	-4.20	0.01	-668.6	1.3
0.4	MC5_L	-4.24	0.00	-674.2	0.5	-4.89	0.00	-714.5	0.5
0.5	EC5T_L	-4.34	0.01	-665.1	0.9	-4.98	0.01	-686.8	0.9
0.5	EC6T_S	-4.33	0.03	-660.1	3.8	-4.35	0.03	-661.2	3.8
0.5	MC5_L	-4.30	0.01	-686.1	1.2	-4.48	0.01	-697.3	1.2
0.6	EC6T_L	-3.88	0.01	-658.2	0.8	-4.36	0.01	-684.7	0.8
0.6	EC7T_S	-4.24	0.03	-667.6	4.4	-4.25	0.03	-668.4	4.4
0.6	MC5_L	-4.27	0.01	-682.9	1.2	-4.45	0.01	-694.8	1.2
0.7	EC5T_S	-4.93	0.03	-669.1	4.2	-4.96	0.03	-670.0	4.2
0.7	EC7T_L	-3.77	0.01	-654.7	0.8	-4.12	0.01	-677.5	0.8
0.7	MC5_L	-4.25	0.01	-682.5	1.1	-4.44	0.01	-694.9	1.1
0.8	EC8R_L	-3.80	0.01	-647.6	2.1	-3.97	0.01	-657.0	2.0
0.8	EC9R_S	-4.16	0.08	---	---	-4.17	0.08		
0.8	MC5_L	-4.18	0.01	-672.2	1.1	-4.39	0.01	-686.1	1.1
0.9	EC8R_S	-4.01	0.04	-615.4	10.6	-4.02	0.04	-615.8	10.6
0.9	EC9R_L	-4.06	0.01	-649.4	3.4	-4.11	0.01	-653.1	3.4
0.9	MC5_L	-4.19	0.01	-668.9	1.0	-4.41	0.01	-683.8	1.0
1.0	EC3B_L	-5.15	0.03	-671.6	3.5	-5.23	0.03	-673.0	3.5
1.0	EC6T_S	-4.24	0.03	-647.9	3.8	-4.26	0.03	-648.9	3.8
1.0	MC5_L	-4.19	0.01	-675.5	1.0	-4.41	0.01	-690.2	1.0
1.1	EC2B_L	-6.53	0.08	-663.4	16.3	-6.80	0.08	-663.7	16.3
1.1	EC5T_S	-4.97	0.03	-655.0	3.9	-5.01	0.03	-656.0	3.9
1.1	MC5_L	-4.21	0.01	-673.6	0.9	-4.49	0.01	-691.7	0.9
1.2	EC1B_L	-7.18	0.11	-646.1	20.6	-7.53	0.12	-646.3	20.6
1.2	EC7T_S	-4.10	0.03	-643.4	4.4	-4.11	0.03	-644.2	4.4
1.2	MC5_L	-4.20	0.01	-672.9	1.1	-4.41	0.01	-687.1	1.0
Avg	---	-4.36	---	-663.4	---	-4.54	---	-672.5	---

Table II. Pulsed Neutron Experimental data with and without detector dead time corrections for YALINA configuration with 21% enriched uranium fuel in fast zone and 1185 EK-10 fuel rods in thermal zone

Config.	Batch	Det.	ρ ($)	Δρ ($)	ρ_c ($)	Δρ_c ($)	ρ_c - ρ ($)	Max. *m* (10^3/s)
(12/ 03/ 2009)	0.1	EC1B	-11.83	0.19	-12.26	0.19	-0.43	44.6
	0.1	EC5T_MCS	-6.37	0.01	-7.20	0.01	-0.84	113
	0.1	EC5T	-6.37	0.01	-7.27	0.01	-0.90	142
	0.2	EC2B	-9.92	0.15	-10.16	0.15	-0.24	382
	0.2	EC6T	-5.47	0.01	-6.00	0.01	-0.54	50.2
	0.2	EC6T_MCS	-5.47	0.01	-5.98	0.01	-0.51	45.5
	0.3	EC3B	-7.48	0.06	-7.58	0.06	-0.11	30.4
	0.3	EC7T_MCS	-5.31	0.01	-5.66	0.01	-0.35	31.6
	0.3	EC7T	-5.30	0.01	-5.68	0.01	-0.38	67.3
	0.4	EC8R	-5.11	0.01	-5.27	0.01	-0.16	14.3
	0.4	EC9R_MCS	-5.47	0.03	-5.51	0.03	-0.05	4.15
	0.4	EC9R	-5.44	0.03	-5.49	0.03	-0.05	4.15
	0.5	MC3	-5.46	0.04	-5.48	0.04	-0.02	1.92
	0.5	MC4	-5.52	0.04	-5.54	0.04	-0.02	2.03
(12/ 17/ 2009)	0.1	EC1BL	-6.04	0.01	-7.64	0.02	-1.60	172
	0.1	EC2BL	-5.68	0.01	-7.09	0.01	-1.41	172
	0.2	EC3B_L	-4.22	0.01	-6.26	0.01	-2.04	184
	0.2	EC9R_L_MCS	-2.95	0.00	-4.58	0.00	-1.64	139
	0.3	EC3B_MCS	-6.98	0.03	-7.52	0.03	-0.54	122
	0.3	EC3B_s	-6.92	0.03	-7.46	0.03	-0.55	148
	0.3	EC9R_s	-5.41	0.01	-5.72	0.01	-0.32	25
	0.4	EC1B_s	-9.28	0.08	-10.55	0.09	-1.27	169
	0.4	EC2B_s_MCS	-8.58	0.07	-9.98	0.08	-1.40	120
	0.4	EC2B_s	-8.53	0.07	-9.49	0.08	-0.96	168
(12/18/ 2009)	0.1	EC1B_s	-9.54	0.08	-10.86	0.10	-1.32	168
	0.1	EC5T_S	-3.65	0.00	-5.31	0.01	-1.66	168
(03/ 23/ 2010)	0.1	EC6T_s	-2.71	0.12	-2.71	0.12	0.00	0.064
	0.2	EC6T_s_Cd	-4.40	0.01	-4.67	0.01	-0.27	101
	0.2	EC7T_s	-3.65	0.00	-5.36	0.00	-1.71	38
	0.3	EC6T_s_Cd	-4.38	0.01	-4.52	0.01	-0.14	62.4
	0.3	EC7T_s	-4.97	0.01	-6.20	0.01	-1.23	92.5
	0.1	EC6T_Cd	-4.53	0.01	-4.92	0.01	-0.39	129
	0.1	EC7T_s	-3.80	0.00	-5.94	0.01	-2.14	154
	0.2	EC6T_s_Cd	-4.27	0.01	-4.59	0.01	-0.32	122
	0.2	EC7T_s	-3.38	0.00	-5.26	0.00	-1.89	152

(03/ 26/ 2010)	0.3	EC6T_s	-2.21	0.00	-3.97	0.00	-1.76	180
	0.3	EC7T_s_Cd	-5.24	0.02	-5.57	0.02	-0.34	54.3
	0.3	EC6T_s	-2.31	0.00	-4.08	0.00	-1.76	181
	0.3	EC7T_s_Cd	-5.33	0.02	-5.65	0.02	-0.32	52.7
	0.4	EC6T_s	-2.59	0.00	-4.47	0.00	-1.88	180
	0.4	EC7T_s_Cd	-5.99	0.03	-6.30	0.03	-0.30	47.8
	0.4	EC6T_s	-2.80	0.00	-4.65	0.00	-1.85	176
	0.4	EC7T_s_Cd	-5.98	0.03	-6.23	0.03	-0.25	40.5
	0.6	EC7T_s_Cd	-5.99	0.03	-6.20	0.03	-0.20	32.9
	0.7	EC7T_s_Cd	-5.37	0.02	-5.55	0.02	-0.18	30.2
(03/ 29/ 2010)	0.4	MC3_s_MCS	-5.25	0.01	-5.51	0.01	-0.27	21.9
	0.4	MC4_s_Cd	-5.79	0.28	-5.79	0.28	0.00	0.19
	0.5	MC3_s_MCS	-5.51	0.02	-5.75	0.02	-0.24	19.4
	0.5	MC4_s_Cd	-6.07	0.10	-6.08	0.10	-0.01	1.19

Table III. Measured reactivity values without and with detector dead time corrections, and the spatially corrected reactivity values with detector dead time corrections of YALINA configurations with 36% and 21% enriched uranium fuel in fast zone and 1185 EK-10 fuel rods in thermal zone

Configuration			Booster zone			Thermal zone			Moderator	Reflector	
			EC1B	EC2B	EC3B	EC5T	EC6T	EC7T	MC5	EC8R	EC9R
36%	Uncor.	L	-7.18	-6.53	-5.15	-4.34	-3.88	-3.77	-4.16	-3.80	-4.06
		S	---	---	---	-4.83	-4.15	-4.09	---	-3.91	-4.16
	Cor. with dead time	L	-7.53	-6.80	-5.23	-4.98	-4.36	-4.12	-4.45	-3.97	-4.11
		S	---	---	---	-4.90	-4.19	-4.12	---	-4.14	-4.17
	Spatially Cor.	L	-5.19	-5.19	-4.54	-4.58	-4.50	-4.39	-4.69	-4.29	-4.30
		S	---	---	---	-4.47	-4.21	-4.14	---	-4.48	-4.50
21% (12/03/2009)	Uncor.	L	-11.83	-9.92	-7.48	-6.37	-5.47	-5.30	---	-5.11	-5.44
	Cor. with dead time	L	-12.26	-10.16	-7.58	-7.27	-6.00	-5.68	---	-5.27	-5.49
	Spatially Cor.	L	-7.22	-7.31	-6.29	-6.58	-6.31	-6.15	---	-5.93	-6.12
21% (12/17/2009)	Uncor.	L	-6.04	-5.67	-4.22	---	---	---	---	---	-2.95
		S	-9.28	-8.58	-6.95	---	---	---	---	---	-5.41
	Cor. with dead time	L	-7.64	-7.09	-6.26	---	---	---	---	---	-4.58
		S	-10.55	-9.98	-7.46	---	---	---	---	---	-5.72

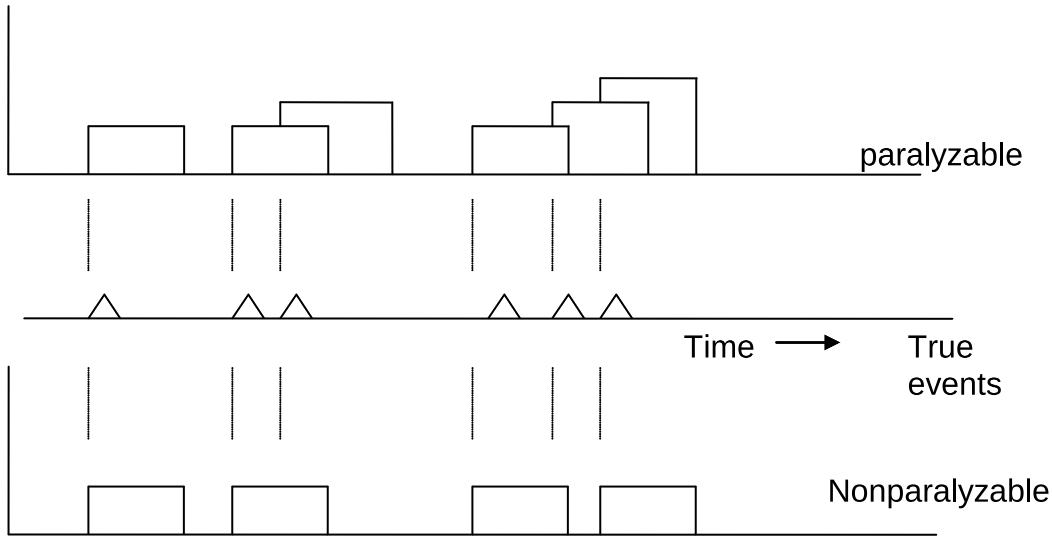

Figure 1. Schematic illustration of the models to correct for the dead time of detector counting systems [1]

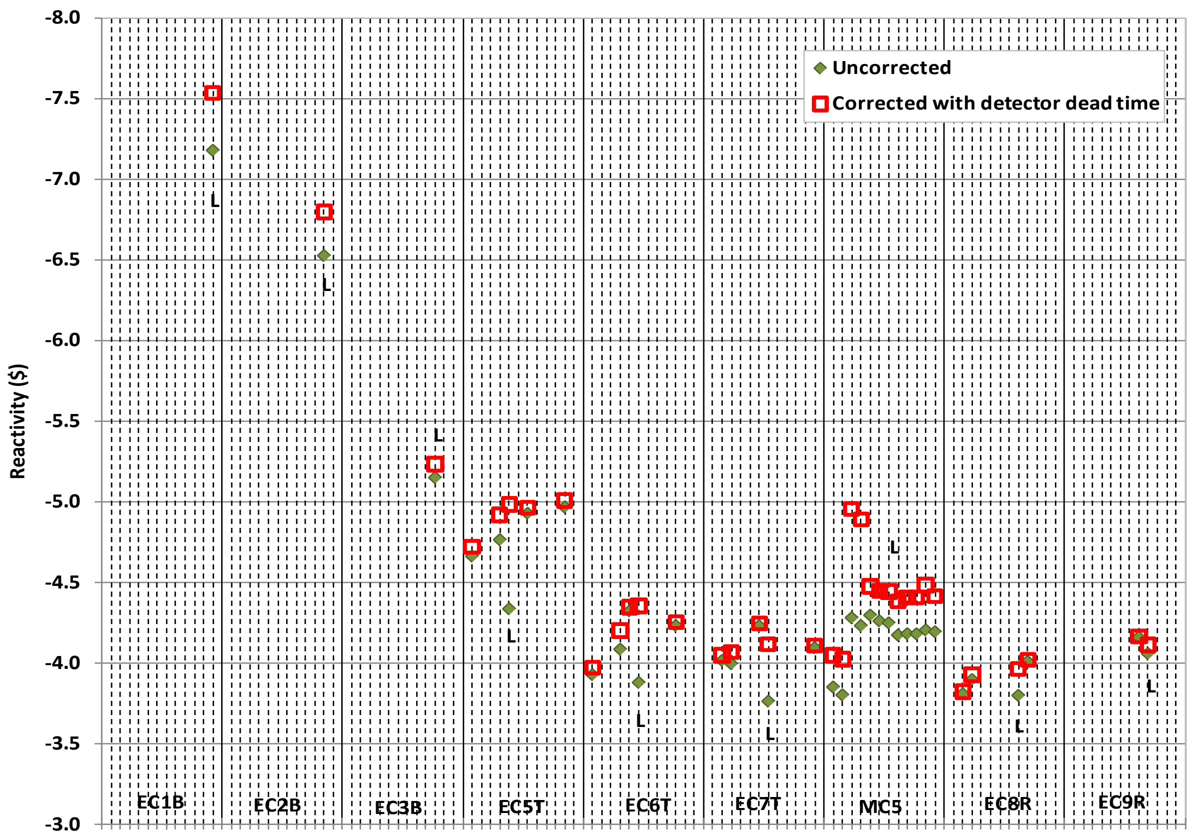

Figure 2. Reactivity values obtained from the pulsed-neutron experimental data with and without detector dead time corrections for YALINA configuration with 36% enriched fuel in the fast zone and 1185 EK-10 fuel rods in the thermal zone

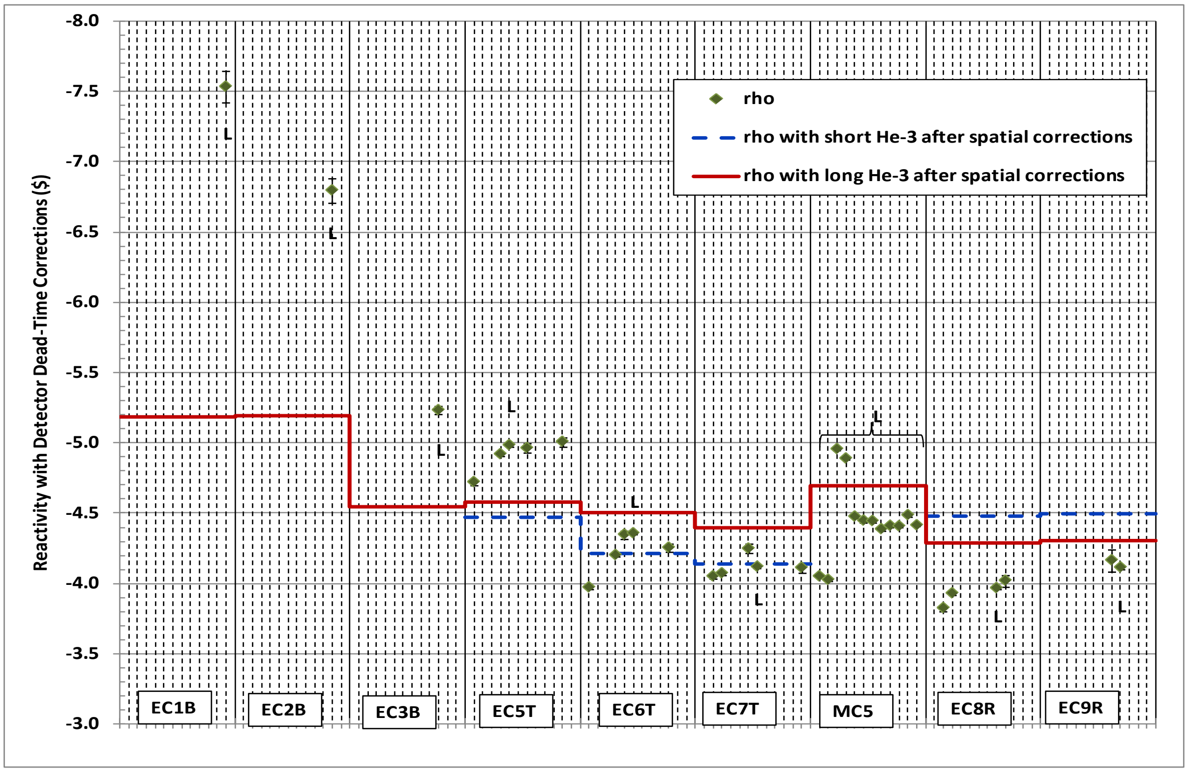

Figure 3. Reactivity values before and after the spatial corrections for the pulsed-neutron experimental data with detector dead time corrections for the YALINA configuration with 36% enriched fuel in the fast zone and 1185 EK-10 fuel rods in the thermal zone

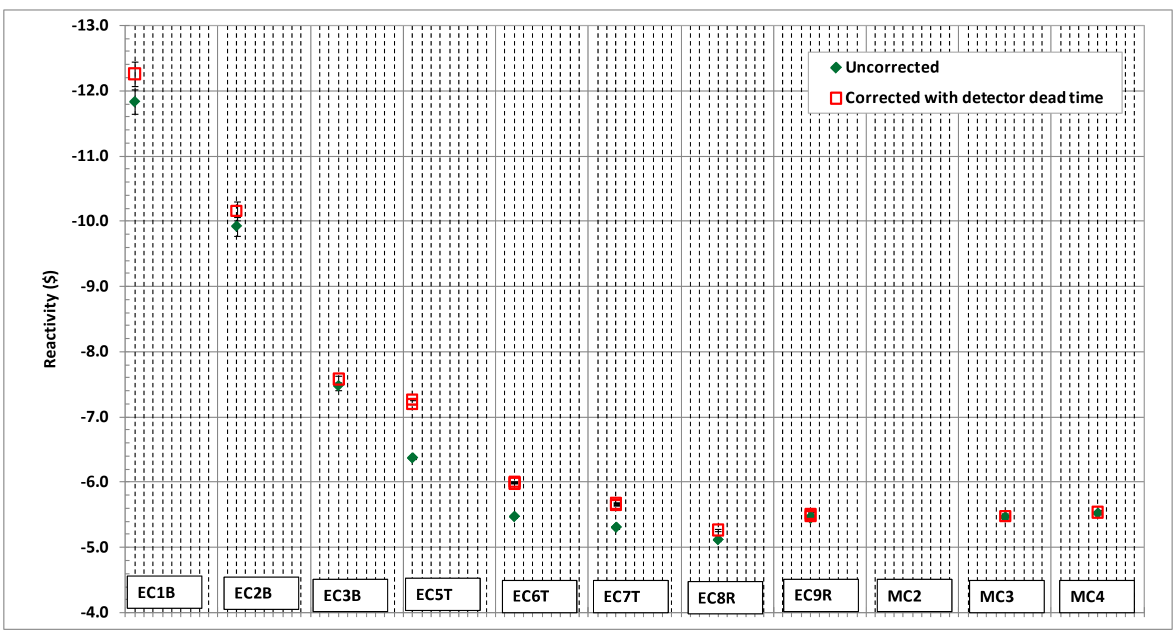

Figure 4. Reactivity values obtained from the pulsed-neutron experimental data with and without detector dead time corrections for the YALINA configuration with 21% enriched fuel in the fast zone and 1185 EK-10 fuel rods in the thermal zone with CR out in December 3, 2009

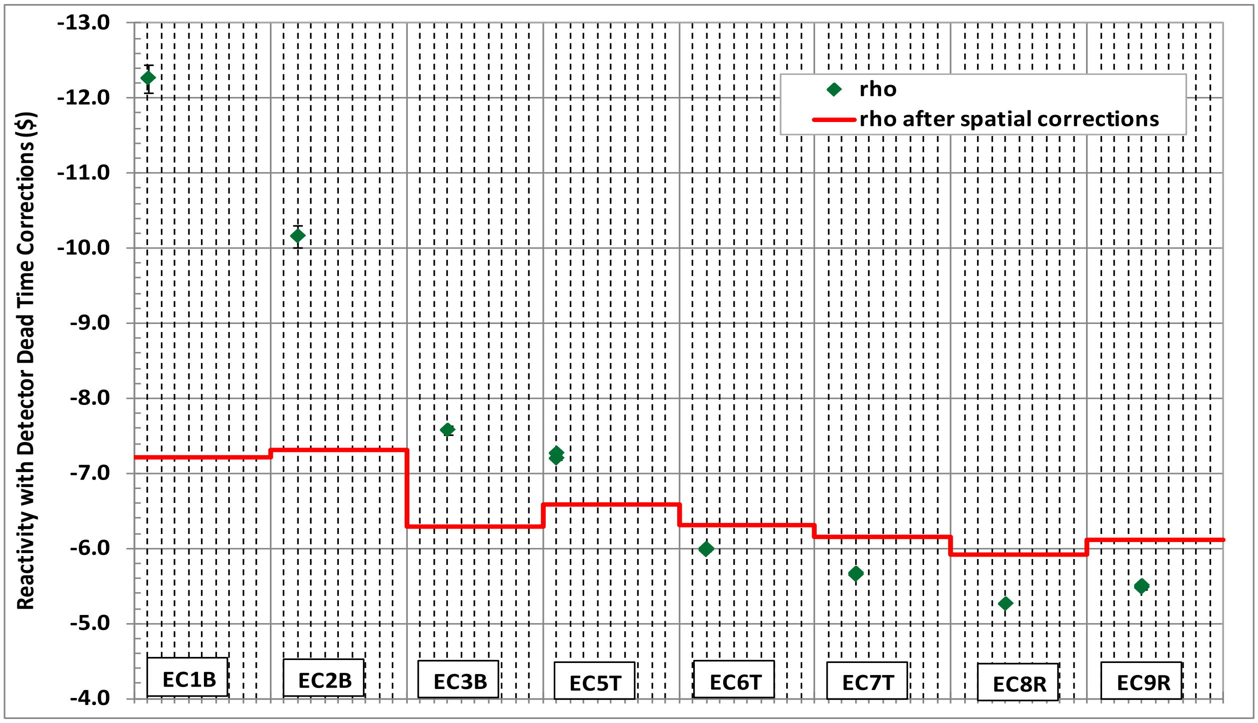

Figure 5. Reactivity values before and after the spatial corrections for the pulsed-neutron experimental data with detector dead time corrections for the YALINA configuration with 21% enriched fuel in the fast zone and 1185 EK-10 fuel rods in the thermal zone with of December 3, 2009

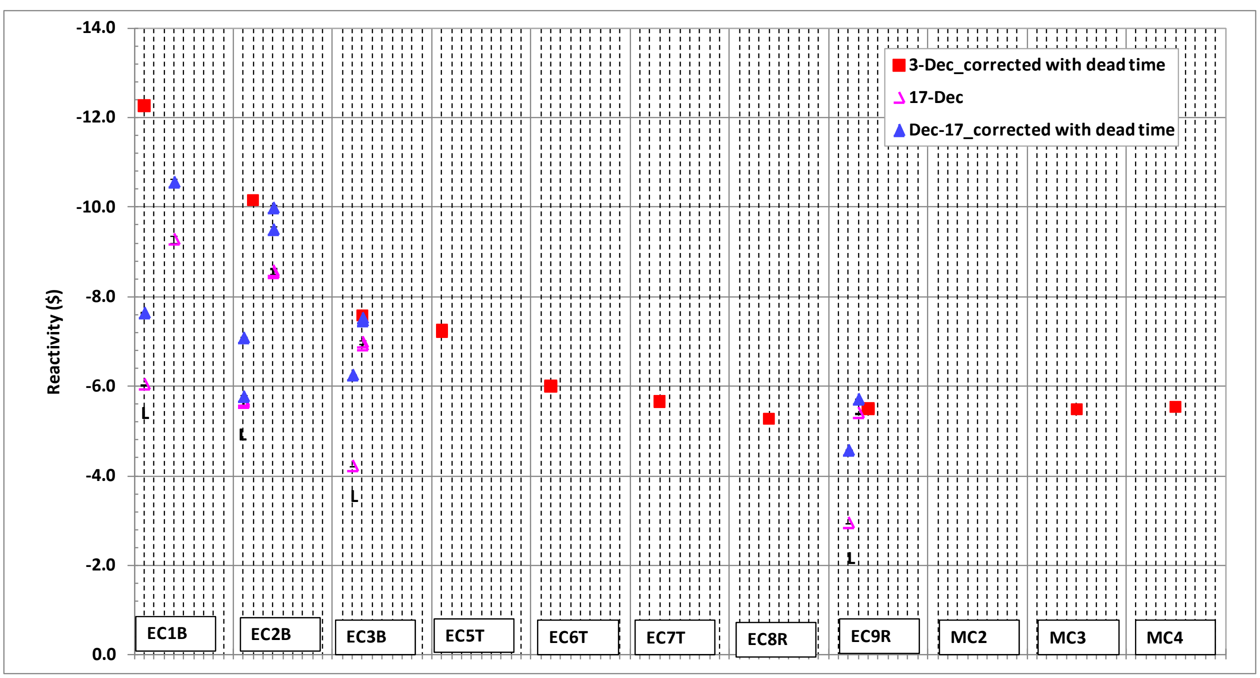

Figure 6. Reactivity values from the pulsed-neutron experiments with and without the dead time corrections for the YALINA configuration with 21% enriched fuel in the fast zone and 1185 EK-10 fuel rods in the thermal zone of December 17, 2009

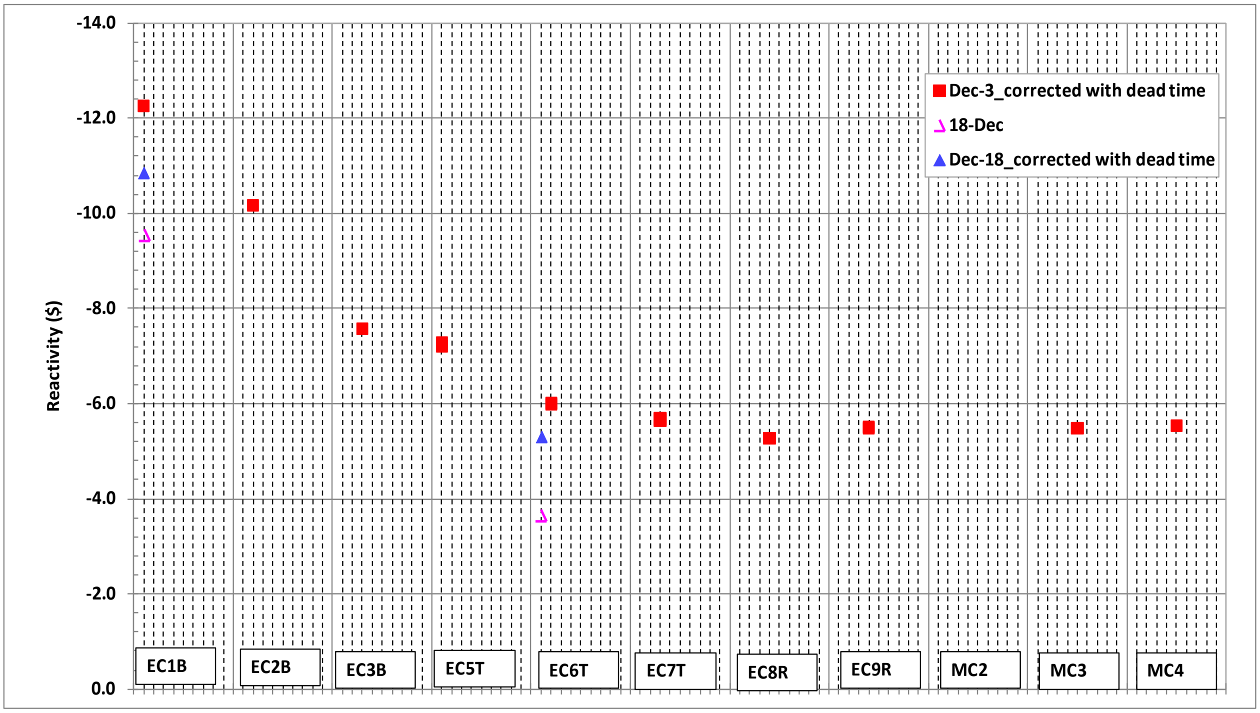

Figure 7. Reactivity values from the pulsed-neutron experiments with and without dead time corrections for the YALINA configuration with 21% enriched fuel in the fast zone and 1185 EK-10 fuel rods in the thermal zone of December 18, 2009

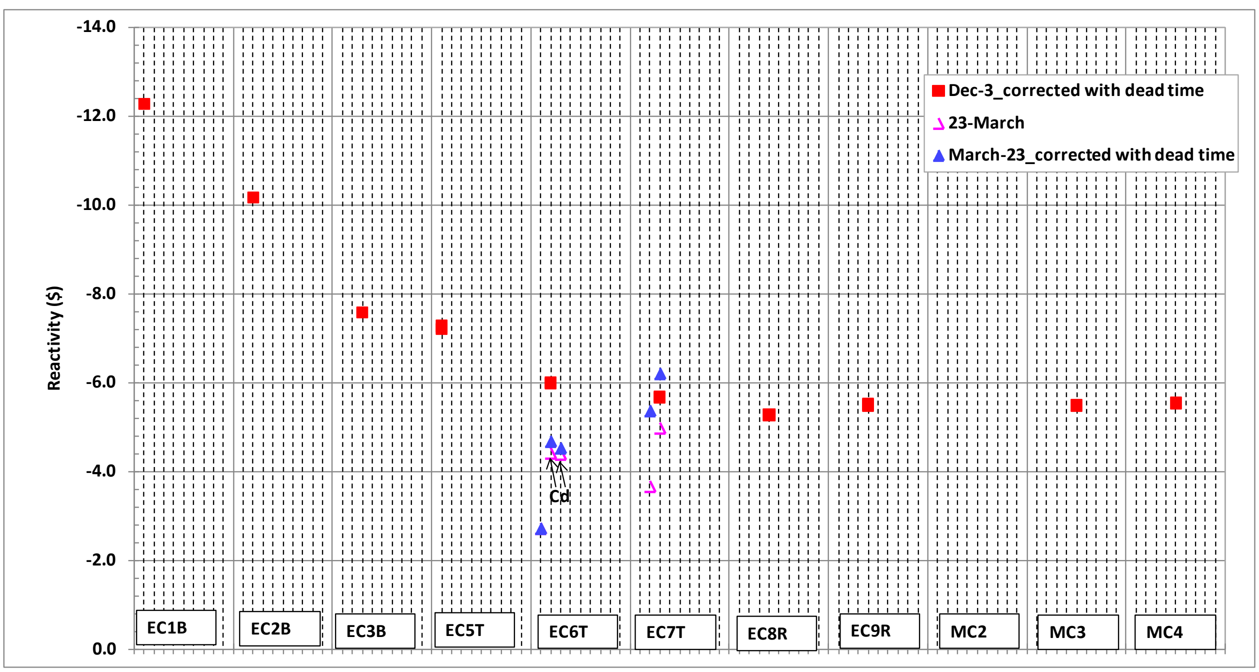

Figure 8. Reactivity values from the pulsed-neutron experiments with and without dead time corrections for the YALINA configuration with 21% enriched fuel in the fast zone and 1185 EK-10 fuel rods in the thermal zone with of March 23, 2010

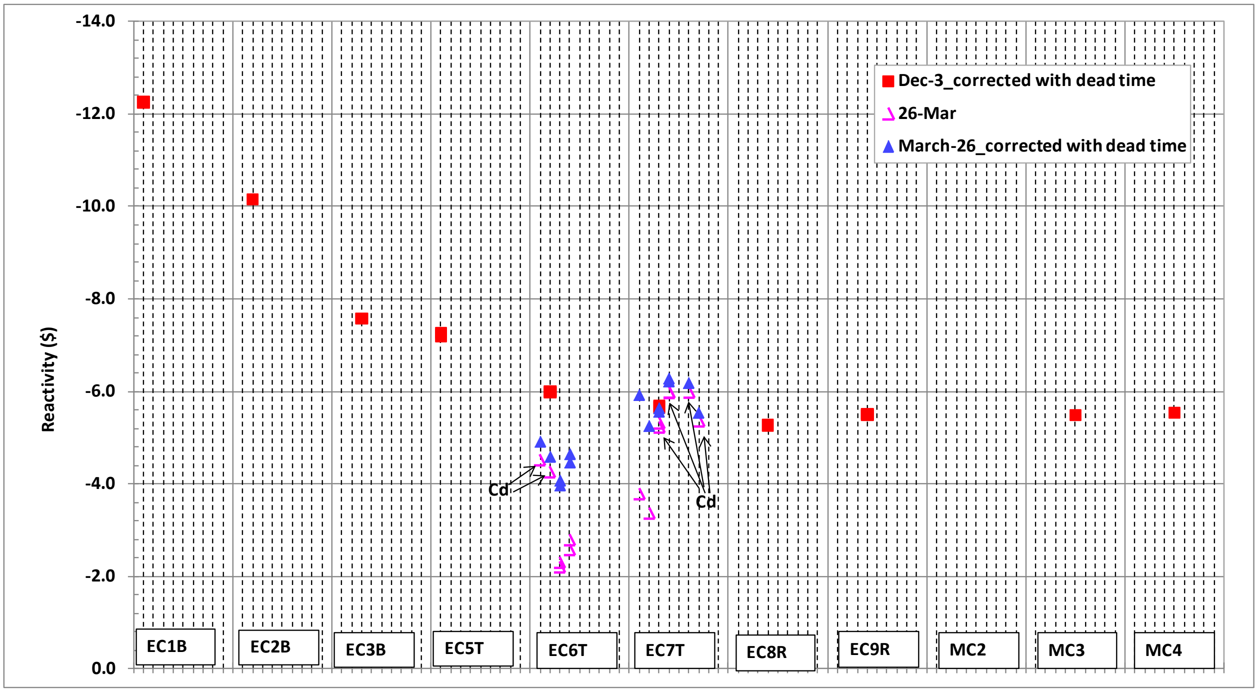

Figure 9. Reactivity values from the pulsed-neutron experiments with and without the dead time corrections for the YALINA configuration with 21% enriched fuel in the fast zone and 1185 EK-10 fuel rods in the thermal zone of March 26, 2010

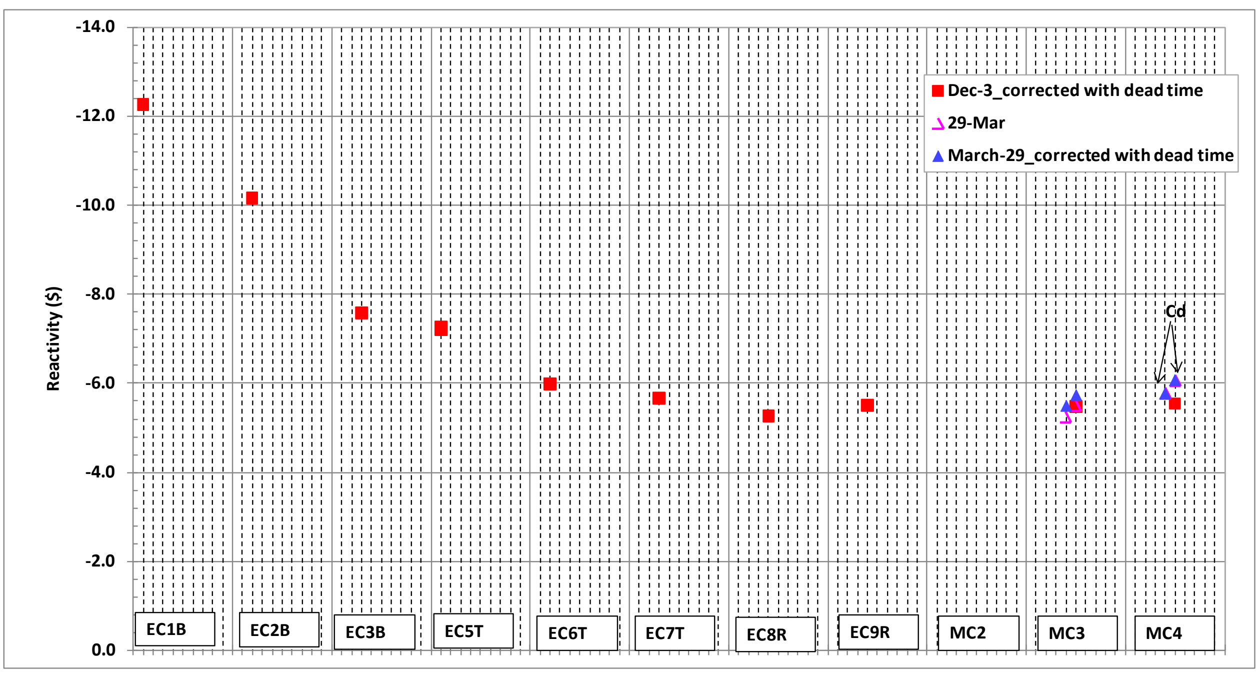

Figure 10. Reactivity values from the pulsed-neutron experiments with and without the dead time corrections for YALINA configuration with 21% enriched fuel in the fast zone and 1185 EK-10 fuel rods in the thermal zone of March 29, 2010

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