Reactivity monitoring of the YALINA subcritical assembly using beam-trips and current-to-power experiments

M. Fernández-Ordóñez, D. Villamarín, V. Bécares, E. González-Romero
Nuclear Innovation Unit, **CIEMAT**-Madrid (Spain)

C. Berglöf
Dpt. Reactor Physics, Royal Institute of Technology, Stockholm (Sweden)

A. Kayivitskaya, V. Bournos, I. Serafimovich, S. Mazanik
JIPNR-Sosny, National Academy of Sciences, Minsk (Belarus)

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MINISTERIO DE CIENCIA E INNOVACIÓN
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

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Motivation

- Transmutation of Spent Nuclear Fuel (SNF) is a key technology for a sustainable nuclear energy.

- One of the explored concepts to reduce the radiotoxicity and volume of the SNF is the Accelerator Driven System (ADS).

- The ADS consists on a subcritical reactor coupled to an ion accelerator providing the neutrons to sustain the chain reaction.

- The reactivity monitoring system for an ADS is of highest importance.

- It is important to determine the best reactivity estimation techniques and the required electronic chains for the measurements.

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Experimental set-up

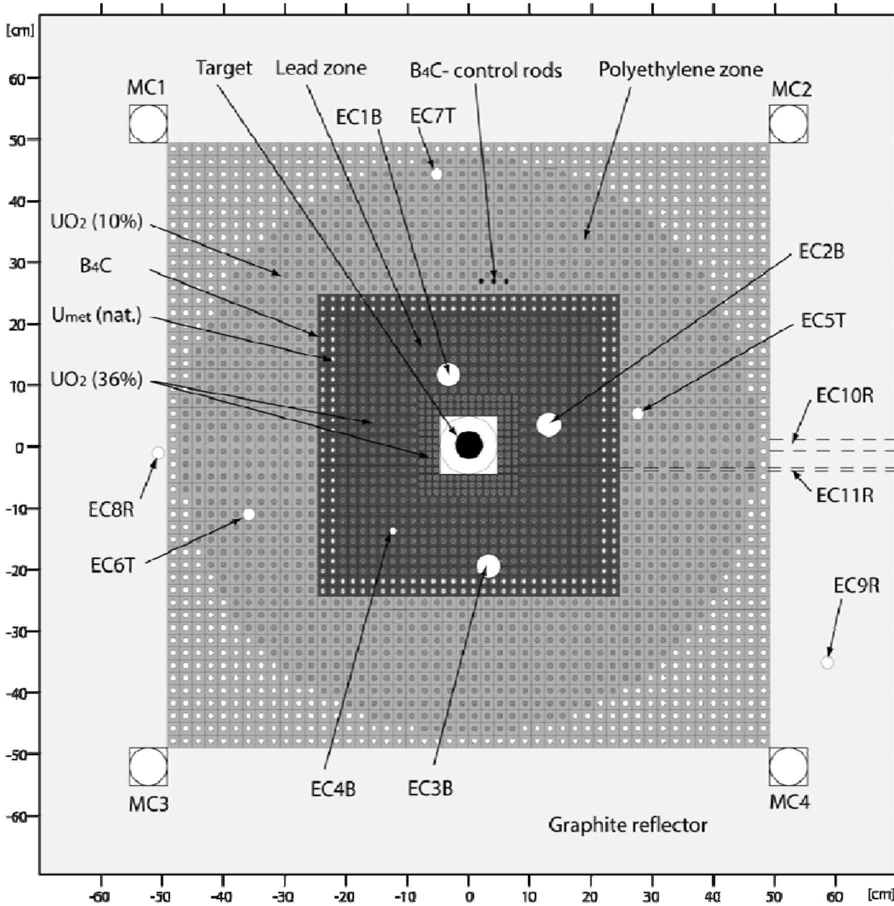
- Subcritical core, deuterium accelerator, tritium target, liquid scintillator and fission chambers.

- Yalina Booster is a subcritical fast-thermal core coupled to a NG-12-1 neutron generator.

- The neutron generator accelerates deuterium ions with a maximum intensity of ~10^{11} neutrons/s. It can be operated in continuous or pulsed modes.

- The continuous wave can be promptly interrupted (~ 1 μs) followed by a fast beam restart.

Experimental set-up



Fast zone:
36% enriched UO_2 in Pb
Thermal zone:
10% enriched UO_2 in a polyethylene matrix
Valve zone:
108 pins of natural U
116 pins of B_4C
Reflector zone:
Graphite

$k_{eff} \sim 0.95$

11 axial experimental channels

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Experimental set-up

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PNS Experiments

- In the PNS experiments, the kinetic evolution of the system is measured after the repetitive injection of short neutron pulses.

- The neutron pulses were 5 μs long and 50 Hz repetition rate.

- We have used two methods to estimate the reactivity of the system from the PNS techniques:

    - Prompt decay constant method.

    - Area method (Sjöstrand method).

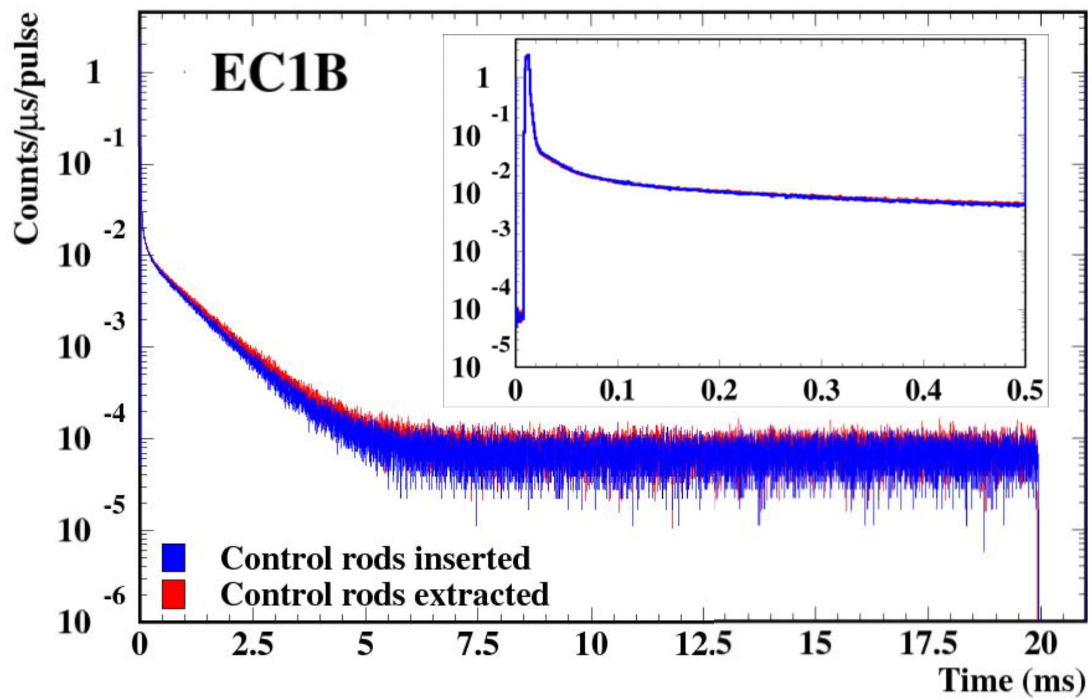
PNS Experiments

Prompt decay constant method

- From point kinetics:

$$-\frac{\rho}{\beta_{eff}} = \frac{\alpha}{\beta_{eff}/\Lambda} + 1$$

- If the ratio β_{eff}/Λ is known, the value of ρ (in units of β_{eff}) can be calculated.



- β_{eff}/Λ is calculated using MCNPX simulations.

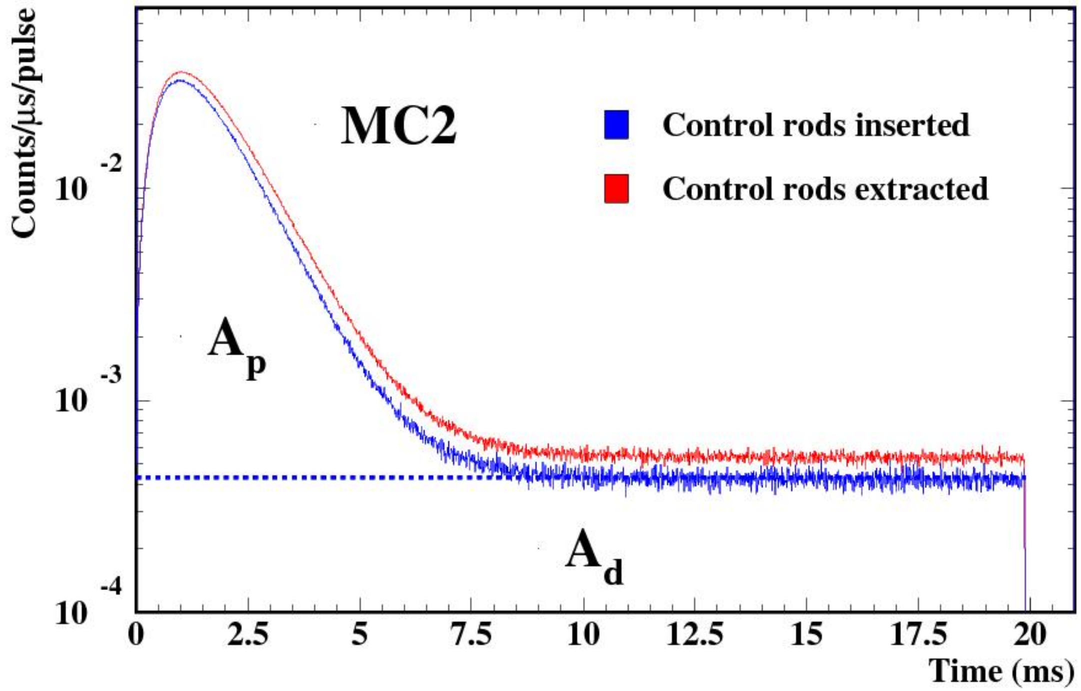
PNS Experiments

Area method

- From point kinetics:

$$\frac{\rho}{\beta} = -\frac{A_p}{A_d}$$

- A_p prompt area
- A_d delayed area



PNS Experiments

- Both methods need some corrections which are calculated with MCNPX 2.5.0 using the JEFF 3.1 libraries.

- With MCNPX we also calculate the magnitudes:

β_{eff} = 683 ± 9 pcm
Λ = 59.7 μs
β_{eff}/Λ = 114 ± 2 s^{-1}
k_{eff} = 0.94906 ± 0.00009
ρ_{MCNP} = 7.86 ± 0.10 $

PNS Experiments

- Results for the area method:

		Control rods extracted		Control rods inserted	
		ρ_{EXP} (\$)	ρ_{CORR} (\$)	ρ_{EXP} (\$)	ρ_{CORR} (\$)
Booster zone	EC1B	-14.93 ± 0.17	- 8.7 ± 0.3	-17.17 ± 0.22	- 10.1 ± 0.4
	EC2B	---	---	-15.30 ± 0.15	-9.9 ± 0.4
	EC3B	---	---	-10.18 ± 0.04	-9.6 ± 0.3
Thermal zone	EC5T	-8.77 ± 0.35	- 10.1 ± 0.6	-9.46 ± 0.21	- 10.9 ± 0.6
	EC6T	---	---	-7.57 ± 0.14	-8.7 ± 0.4
Graphite reflector	MC2	-7.26 ± 0.03	- 9.0 ± 0.3	-7.88 ± 0.06	- 9.8 ± 0.4
	MC3	-7.33 ± 0.96	- 8.5 ± 1.2	-7.96 ± 1.13	- 9.3 ± 1.4

PNS Experiments

- **Taking the average of all the detectors:**

	C.R.Extracted	C.R.Inserted
Prompt decay method	8.7 ± 0.3	9.3 ± 0.3
Area method	9.0 ± 0.2	9.7 ± 0.2

The results obtained from both methods are very close

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Current-to-power experiments

- **Key point for ADS**: robust on-line and continuous monitoring of the subcritical reactivity:

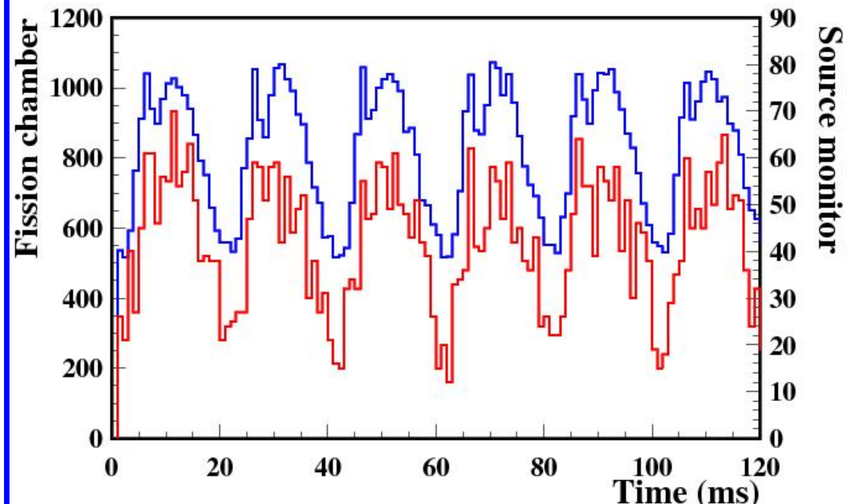
$$P = -q\varphi \frac{S}{\rho} \quad \Longrightarrow \quad -\rho = q\varphi \frac{S}{P}$$

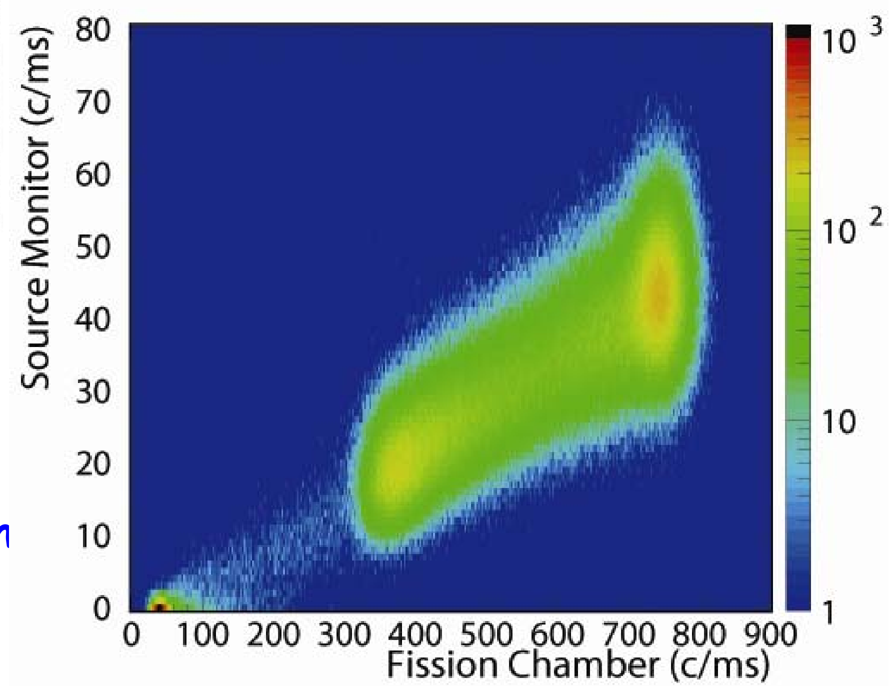
where P is the reactor power, φ represents the source importance, S(I,……) is the source intensity and q denotes the energy released by fission.

- The on-line determination of the reactivity requires the monitoring of three quantities: The core power (P), the deuteron accelerator intensity (I) and the neutron source (S).

Current-to-power experiments

- Several factors can spoil this proportionality.





- The power (P) is closely proportion
to the accelerator current (I).

- With our system we can monitor
short as 1 ms.

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Beam-trip experiments

- Current-to-power technique can only provide relative changes in the reactivity of the system. It is necessary to use absolute reactivity determination techniques.

- Using beam-trips is possible to apply source-jerk or prompt decay constant methods.

- We can achieve beam-trips of ~ 40 ms length and 1 Hz repetition rate.

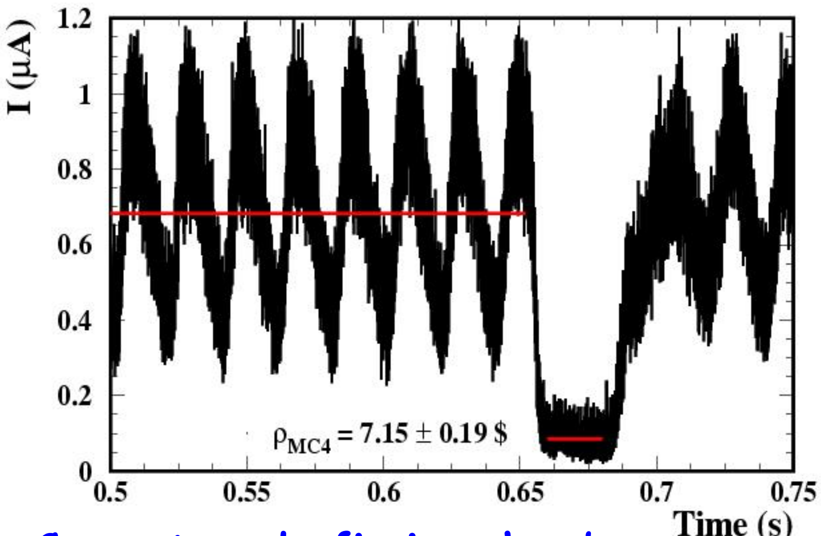
- Pulsed mode electronics can limit the accuracy due to dead-time.

- We have developed the necessary electronic chain to measure with the fission chambers operating in current mode at high sampling rate.

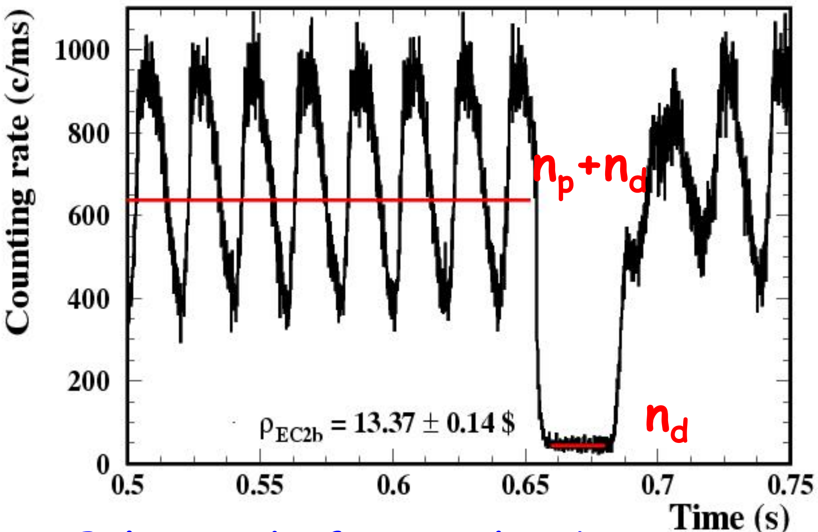
Beam-trip experiments (single beam-trip)

Source jerk method:

$$\frac{\rho}{\beta} = -\frac{n_p}{n_d}$$



Current mode fission chamber



Pulse mode fission chamber

Single beam-trip !

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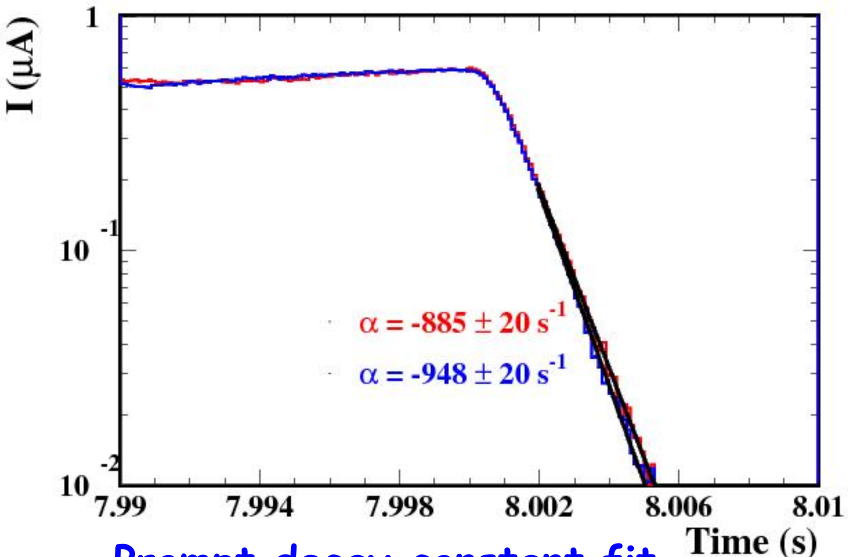
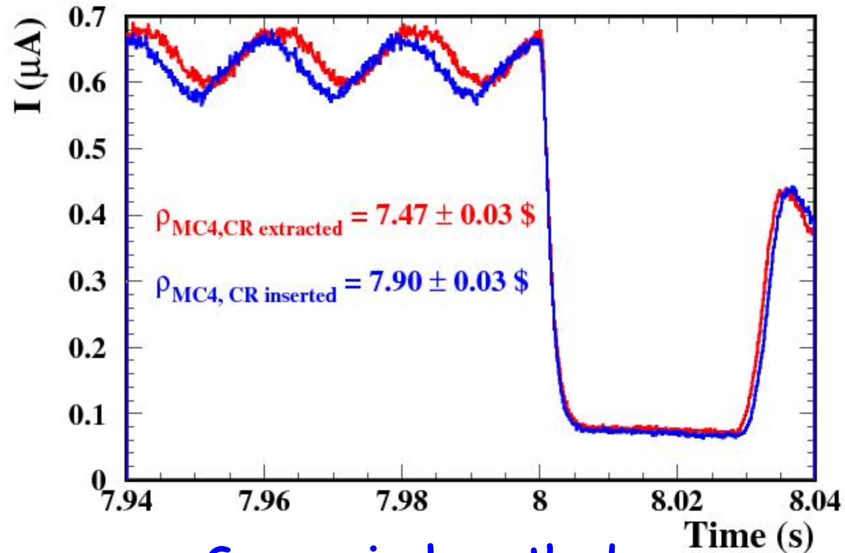
Beam-trip experiments (averaging beam-trips)

Current mode fission chamber



Prompt decay constant fit



Source jerk method

Averaging of 50 pulses.

Summary and conclusions

- The reactivity of the Yalina configuration has been calibrated by PNS techniques, obtaining compatible results from the area and prompt decay constant methods.

- The 14 MeV neutron source was monitored with a liquid scintillator at intervals as short as 1 ms.

- The intensity of the neutron source is not always proportional to the beam current of the accelerator and we were able to identify these situations.

- Despite of the adverse experimental conditions we were able to perform measurements with fission chambers in current mode, with currents below 1 μA.

- Applying the source-jerk technique in current mode detectors (for the first time) we have obtained reactivity values from a single beam trip very close to those obtained with standard pulsed detector.

Thanks for your attention !