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ONLINE MEASUREMENT OF PARAMETERS RELEVANT FOR ADS MONITORING: EXPERIMENTAL TECHNIQUE VALIDATION IN MASURCA

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To operate systems such as ADSs, kinetics parameters will have to be monitored. It is one of the aim of the MUSE experimental program to investigate techniques to do so. Taking advantage of piloting the accelerator GENEPI coupled to the MASURCA reactor it is possible, by varying suddenly the source intensity from a high to a low level, to access the ρ/β_{eff} parameter. Together with a measurement of the prompt multiplication factor k_p it is then possible to obtain the absolute values of β_{eff} and k_{eff} of the reactor. This method applied for two reactivity levels shows very good agreement with classical measurements performed in critical configurations.

1. Introduction

The monitoring of ADS kinetic parameters will require development of dedicated techniques. Among the objectives of the MUSE-4 experimental program, investigation and comparison of experimental methods to measure the multiplication factor k_{eff} and the delayed neutron fraction β_{eff} are main subjects of interest.

The coupling of a pulsed neutron source (the GENEPI generator) to the MASURCA reactor loaded to be subcritical gives a tool to study dynamical parameters of the reactor. Since only the fraction $(1-\Sigma_i\beta_i)$ of the fission neutrons is prompt, the total multiplication factor k_{eff}, which governs the safety of the reactor is related to the prompt multiplication factor k_p by the equation:

$$k_p = \left(1 - \sum_i \beta_i\right) k_{eff} . \quad (1)$$

We have already shown that Pulsed Neutron Source (PNS) techniques together with MCNP simulations could be used to determine the k_p value of a subcritical assembly [1-2]. We have thus developed an experimental procedure to determine the delayed part of the multiplication factor to fully qualify the time behavior of the multiplying medium.

2. Experimental Setup

The MASURCA reactor facility (CEA Cadarache, France) is a small fast reactor devoted to experimental reactor physics research. It can operate in critical or subcritical configuration by changing the number of fuel assemblies. The core central zone consists of MOX fuel (UO_2, PuO_2) and Na rodlets. The reflector is made of Na and stainless steel (SS), and the shielding of SS. A cut in the horizontal plane is shown in Fig. 1. The two experimental configurations of measurement were corresponding to reactivity levels of about -500 pcm[a] (called SC0) and -3000 pcm (SC2). The Fig.1 shows the SC0 configuration and the fuel assemblies removed in the peripheral zone to achieve the SC2 configuration. A pilot rod (PR) can be inserted or removed from the core, allowing a maximum reactivity change of about 150 pcm. Measurements presented here were performed with the PR down.

The external neutron source was provided by a 250 kV pulsed deuteron accelerator: the GENEPI generator. After a magnetic analysis, accelerated deuterons are guided through a thimble inserted into the core onto a titanium-tritium target, creating $T(d,n)^4He$ reactions. The peak intensity of the pulses is about 40 mA, and their time width is smaller than 1 μs. The source repetition rate can vary from a few Hz up to 5 kHz, providing about $3.3.10^9$ neutrons/s at 1 kHz.

The reaction rate measurements were performed with a CEA fission chamber (^{235}U deposit) located in the core (detector 4 in Fig.1).

[a] One pcm unit corresponds to a reactivity of 10^{-5}.

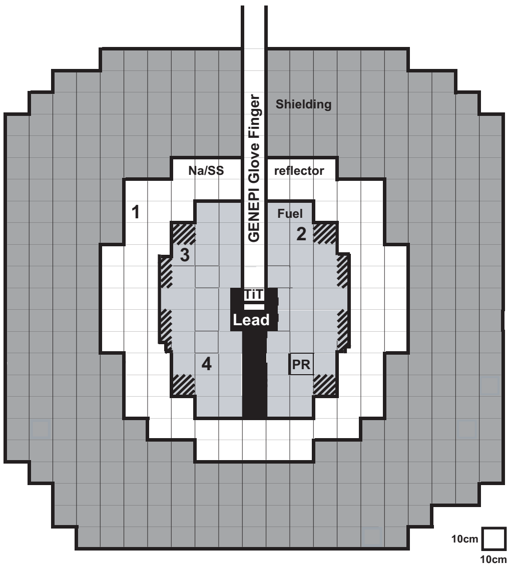

Figure 1. XY cut in the median plane of MASURCA core in the SC0 configuration. The dashed areas represent the fuel removed for the SC2 configuration. The scale of a single fuel assembly is shown in the right bottom of the figure.

3. Measurement of the Effective Delayed Neutron Fraction

3.1. *Overview of the Experimental Method*

The method applied is closely related to the "Source Jerk" technique. During an irradiation time (T_{irr}=200 s) much larger than the half-life of the "longest lived" neutron precursor (56 s), the GENEPI generator is operating at a repetition rate F_0= 4 kHz, thus injecting into the subcritical assembly a neutron source rate S_0 proportional to this frequency. Consequently, the subcritical system is maintained at neutron and precursor population equilibrium, n_0 and C_{i0} respectively, by the extraneous neutron source S_0. In such a case the neutron balance equation writes:

$$\left(\frac{\rho-\beta_{eff}}{\Lambda}\right)n_0+\sum_i \lambda_i C_{i0}+S_0=0 \qquad (2)$$

where Λ is the mean fission generation time, C_{i0} is the equilibrium concentration of the i^{th} delayed neutron precursor, and λ_i is the decay constant of the i^{th} precursor. Let now imagine, for sake of simplicity, that the external source is suddenly switched off. Following this sudden change in the source intensity, the prompt neutron flux dies away quickly and the flux then reduces to the delayed neutron flux decreasing with precursors' time constants. Under these conditions, a simple result can be obtained, by merely assuming that the concentration of the delayed neutron C_{i0} does not change over the time of the sudden drop in the flux. The neutron density n_1 immediately after the sudden change in source intensity is given by:

$$\left(\frac{\rho - \beta_{eff}}{\Lambda}\right) n_1 + \sum_i \lambda_i C_{i0} = 0 \qquad (3)$$

because the delayed neutron precursor population will not change immediately. These equations and the equilibrium precursor concentrations:

$$C_{i0} = \frac{\beta_i n_0}{\lambda_i \Lambda} \qquad (4)$$

lead to the equation:

$$\frac{\rho}{\beta_{eff}} = 1 - \frac{n_0}{n_1}. \qquad (5)$$

3.2. *Experimental Procedure*

The ratio n_0/n_1 is obtained experimentally as the ratio of detectors counting rates which suffer the following effects:

- the inherent source of the reactor gives birth to a constant counting rate due to spontaneous fissions and (α,n) reactions on U and Pu oxides
- the return phase to the high frequency must be adapted to the reactor doubling time (5 s) on pain to cause a safety rod drop. Consequently, the source is not switched-off but varies from a high value F_0 (4 kHz) to a low value F_1 (300 Hz) in order to decrease the time needed to reach F_0 from the low frequency F_1 (see Fig. 2).
- the choice of the low frequency F_1 is also based on a physical ground: it corresponds to a time interval of 3 ms between two consecutive neutron pulses. This time distance must be compared to the half-live of the shortest-lived delayed neutron precursors: thanks to the weak interaction properties no β emitters in the mass range of the fission products have a half-life shorter than a few tens of milliseconds. As a consequence, even for the shortest-lived delayed neutron precursors, the pulsed irradiation acts as a continuous one.

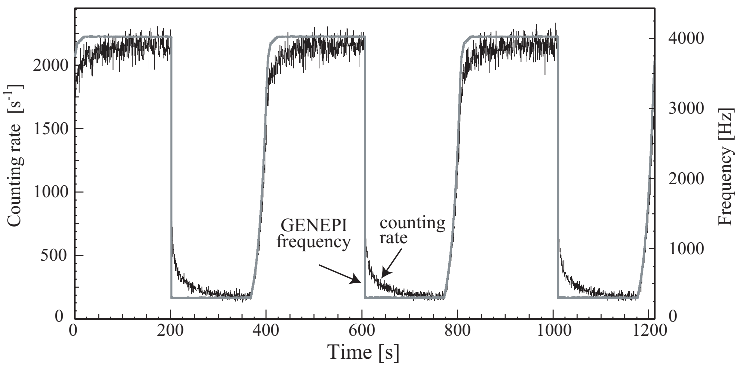

Figure 2. Source frequency variation cycle (gray line, right scale) and experimental neutron counting rate (black line, right scale) for three cycles.

Under these conditions, the rates n_0 and n_1 which enter the Eq. (5) are replaced by the quantities R_0 and R_1 obtained by subtracting to the total counting rates a pedestal which consists of the sum of the inherent source and of the equilibrium rate corresponding to the low excitation frequency F_1, as shown in Fig. 3.

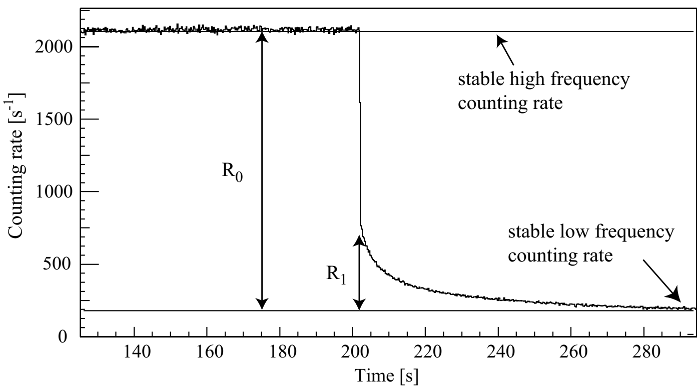

Figure 3. R_0 and R_1 quantities (summation over all measured transients) obtained with detector 4 in the SC0 configuration.

We should emphasize that the transition from the high to the low frequency level occurs in less than 100 ns which is much shorter than the time needed to withdraw the source in classical source jerk experiment. This makes the method free of corrections related to the jerk time.

4. Results

Fig. 4 shows, for the two core configurations SC0 and SC2, the results of the source modulation experiment. The two displayed spectra correspond to the sum of all measured transients for a given subcriticality. These data allow us to extract a value of ρ/β_{eff} following Eq. (5). With the value of the prompt multiplication factor deduced from the prompt decay analysis [1], the Eq. (1) along with the Eq. (5) leads to:

$$\beta_{eff} = \frac{1-k_p}{1-\left(\frac{\rho}{\beta_{eff}}\right)_{\exp}} \quad (6)$$

Finally, the effective multiplication factor k_{eff} is calculated for the different configurations and is compared to the value obtained with standard Source Multiplication (SM) methods [3]. All the results and SM values are gathered in Table 1.

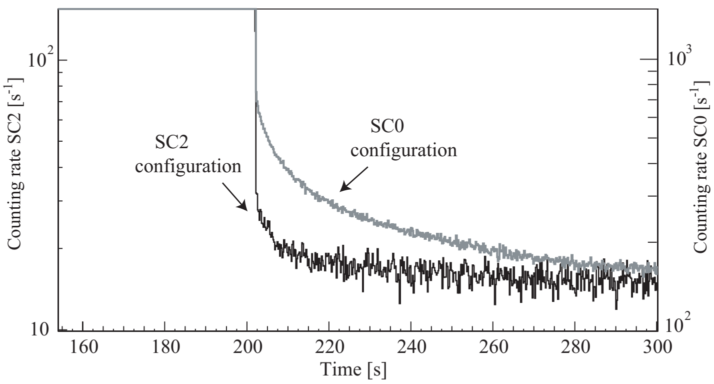

Figure 4. Delayed neutron contribution to experimental counting rates measured with detector 4 for the SC0 configuration (gray line, right scale) and SC2 configuration (black line, left scale).

Table 1. β_{eff} and k_{eff} values for the SC0 and SC2 configurations the pilot rod down compared to k_{eff} values obtained with standard SM measurements [3].

Configuration	β_{eff} (pcm)	k_{eff}	k_{eff} (SM)
SC0 PR down	330±30	0.9921±0.0013	0.9937±0.0005
SC2 PR down	300±30	0.9703±0.0023	0.9716±0.0030

There is excellent agreement between the SM results and those obtained with our proposed method, but also a good agreement of β_{eff} with other measurements analyzed with CPSD (Cross Power Spectral Density) method and giving 334±6 pcm [4].

In addition to these results, a careful analysis of the slow decrease (Fig. 4) of the neutron counting will allow us to measure the distribution of emission times for the delayed neutrons and compare it with the spectrum which can be constructed from the precursor decay data.

5. Conclusions

In the MUSE project, a pulsed deuteron generator was coupled to the MASURCA fast reactor to establish a subcritical assembly driven by a pulsed neutron source. We have developed and successfully applied a method which allows us to determine the ratio of the absolute reactivity ρ to the fraction of delayed neutron β_{eff}. Together with the complementary method we developed to measure the prompt multiplication factor k_p, it gives access to the parameters which governs the prompt and the slow kinetics of a subcritical assembly. Thanks to the fact that these methods do not require any calibration measurement in critical configuration, it can be used for the monitoring of a future ADS. This work highlights the ability of an external pulsed source for the characterization of any fuel assembly even devoted to critical systems.

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