A new βeff measurement system using the Californium Source Method

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Introduction:

The fast neutron zero-power reactor VENUS-F [1] supports research into a new reactor design MYRRHA by verifying calculation codes and nuclear data. Research with VENUS-F, presented in this work, provides an insight into the time-dependent behavior of a nuclear reactor by experimentally determining kinetic parameters. The effective delayed neutron fraction β_{eff}, which expresses the share of delayed neutrons among all fission neutrons in the reactor, weighted with their importance, is determined with the Californium Source Method [2]. The neutron noise method (the Rossi-α method) is performed to determine the mean neutron generation time Λ, which is the average time from neutron production until absorption inducing fission. In addition to the measurement of the β_{eff} and Λ values, their uncertainties are also determined.

Strenght S_{cf}

The isotope ^{252}Cf ($T_{1/2}$ = 2.6 y) is used as a neutron source that emits fast neutrons originating in the spontaneous fission process. The strength of the ^{252}Cf source can be calculated based on the certificate data. On the day of the measurement the neutron source had a strength of 3.75 x10^5 n/s.

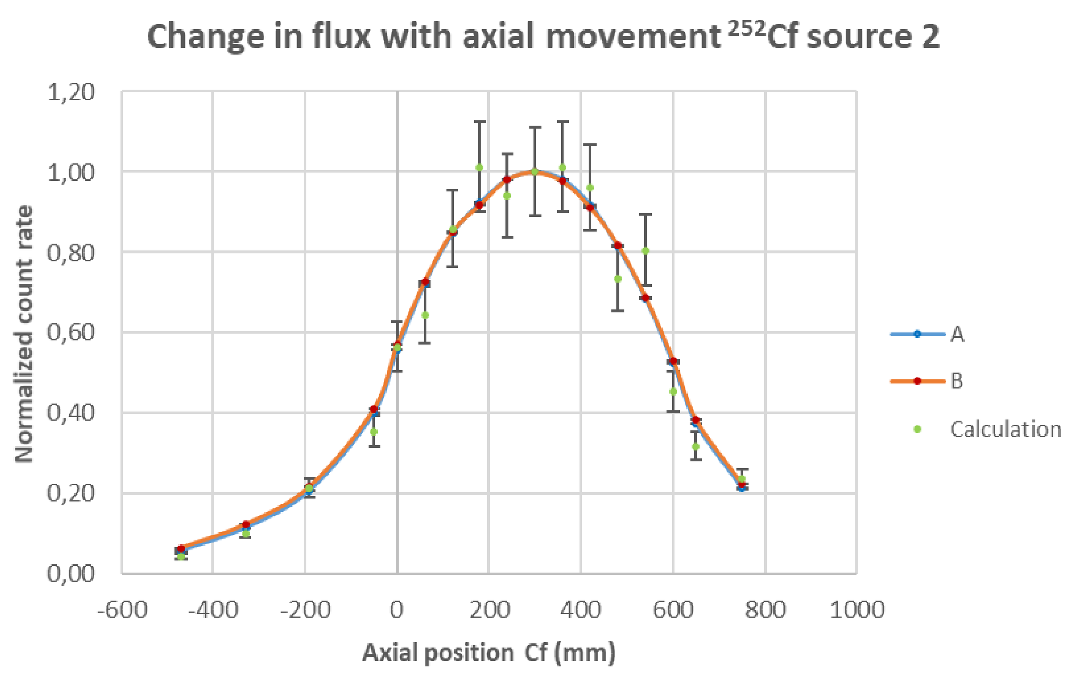
Change in fission rate Q_f

The Cf-source is inserted in the center of the VENUS-F reactor. That causes a chnage in fission rate that is measured with a detector positioned in the assembly next to the assembly containing the californium source. The change in fission rate is determined for three subcriticality levels. For every subcriticality level, the background count rate (without the presence of the Cf-source) is measured. Afterwards, the average change in fission rate is calculated for a critical core through correction of the three subcriticality levels.

Calculation of f, $\overline{\nu}$ and $F^{+}_{\chi,cf}(0)/\overline{F^{+}_{\chi}}$

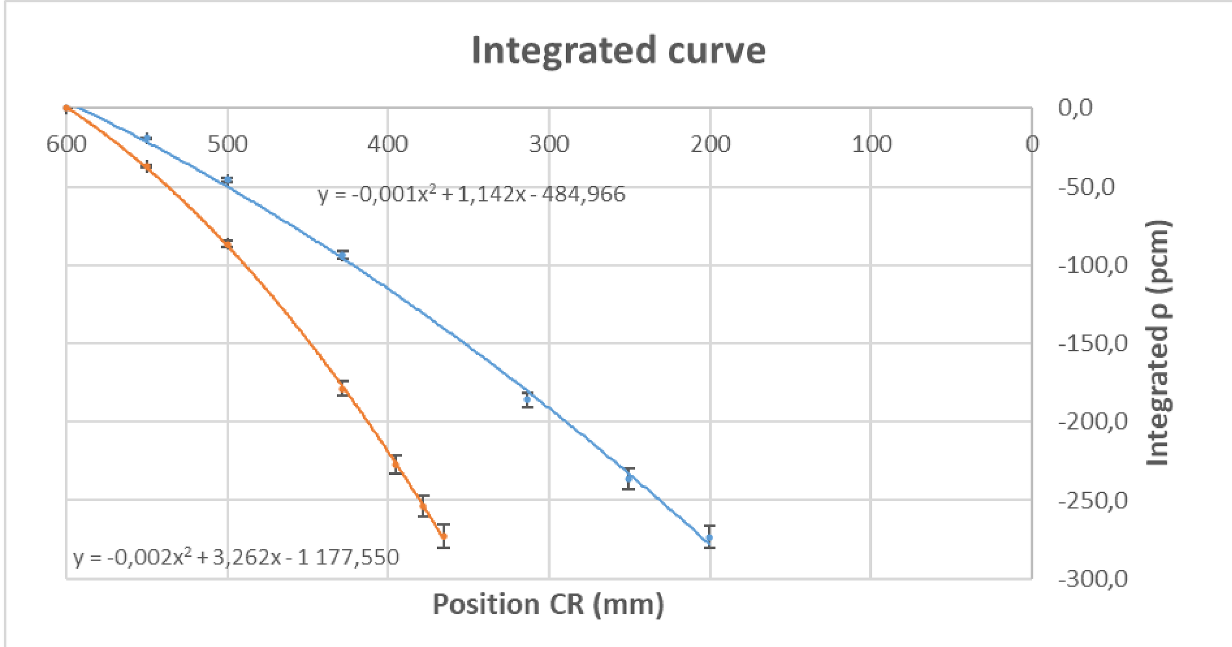
To simulate the CC12 reactor core, Serpent2 [3] Monte Carlo Code is used. Firstly, a critical core composition is simulated to calculate k_{eff}, β_{eff}, $\overline{\nu}$ and the relative abundancy of the precursor groups $a_{i,eff}$ with their respective decay constants λ_i. Then, the k_{eff} for the three subcriticality stated is calculated. For the three subcriticality states new calculations where the external californium source is present are made to determine the factors used in the Californium Source Method: f (conversion factor between the central fission rate measured by the absolute fission chamber and the fission rates in the whole reactor) and (ratio of $F^{+}_{\chi,cf}(0)/\overline{F^{+}_{\chi}}$ the introduced 252Cf neutron importance at the core center to reactor averaged neutron importance).

To verify if the calculated correction factors are reliable and representative for the whole reactor core extra experiments are performed. These experiments are axial dependent measurements when the californium source or the detector is moving from the bottom reflector to the top reflector.



Subcriticality $\rho_\$$

The subcriticality $\rho_\$$ of the VENUS-F core is measured with calibrated control rods. The calibration is performed using the positive period method combined with the compensation method. Then the calibrated control rods are used to measure the reactivity of the selected sub-criticality states.



The Californium Source Method

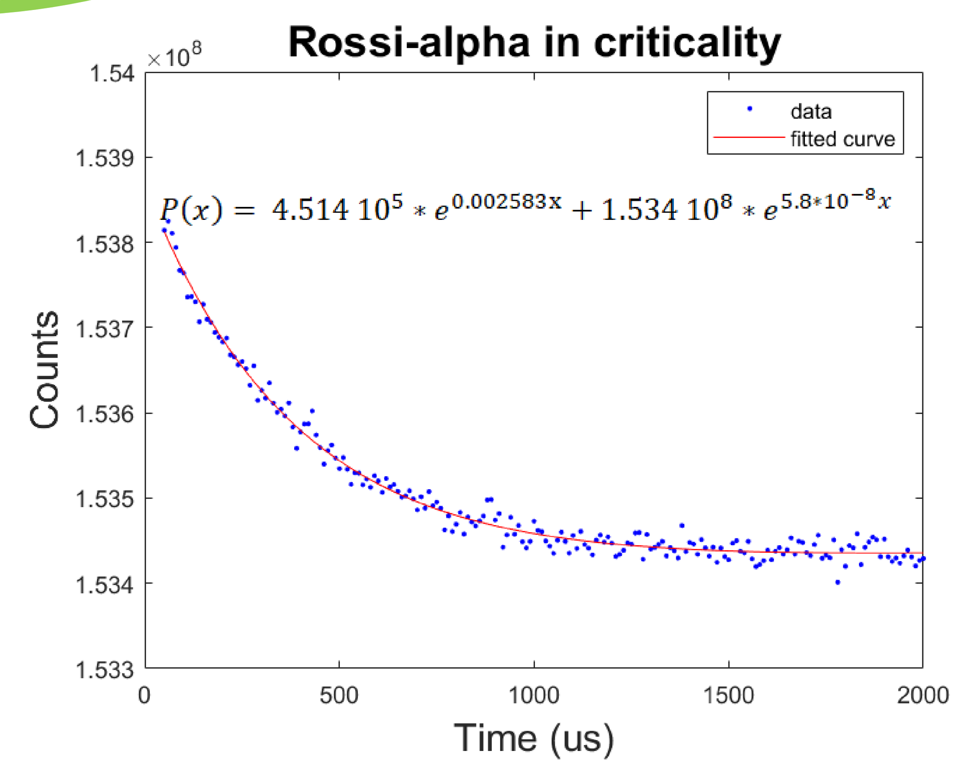
$$\beta_{eff} = \frac{S_{cf}}{|\rho_\$| * Q_f * \overline{\nu}} * \frac{1}{f} * \frac{F^{+}_{\chi,cf}(0)}{\overline{F^{+}_{\chi}}}.$$

ρ (cents)	-13.71	-19.03	-23.96
S_{Cf}		375000	
Q_f	1793.48	1298.29	1039.41
$\overline{\nu}$		2.51169	
f	1.01E+05	1.00E+05	1.02E+05
$F^{+}_{\chi,cf}(0)/\overline{F^{+}_{\chi}}$		1.183	
β_{eff}	710	713	695

The average β_{eff} is 706 pcm with an uncertainty of 5%.

The Rossi-α Method

The Rossi-α method [4] is based on the phenomenon of measuring a time correlation between a neutron and each subsequent neutron within a time frame. This means that in a short period of time after the measurement of a neutron, there is a greater probability that additional neutrons will be detected than later in time. This probability Pt can be described by a decreasing exponential function with the prompt neutron decay constant as a coefficient α:



$$P_t = a + b * e^{-\alpha * t}$$

By measuring the coefficient α with the Rossi-alpha method and β_{eff} with the Cf source method, it is possible to calculate the mean neutron generation time Λ.

$$\alpha \approx \frac{\beta_{eff}}{\Lambda}$$

The calculated mean neutron generation time is 2781 ns with an uncertainty of 5%.

Conclusion:

A measurement system for determination of the effective delayed neutron fraction β_{eff} using the ^{252}Cf-source method was developed and tested at the zero-power VENUS-F reactor. Additional experiments were made using the Rossi-α neutron noise method to determine the mean neutron generation time Λ. Monte Carlo simulations with the Serpent2 code were performed to calculate correction factors and the kinetic parameters for comparison with the experiments. After application of the calculated parameters, the final value of β_{eff} was determined to be (706 ± 32) pcm. Serpent2 gives a value that is about 6% bigger, which agrees with the experiment within 2s. The final value of Λ is (2781 ± 150) ns. Serpent2 gives a value that is 29% smaller, which represents more than 5s. That indicates either a problem in the simulation or in the application of the Rossi-a method, which requires further investigation.

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References
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