CF-252 SOURCE-DETECTOR METHOD FOR ADS AND CORE RELOAD IN NPP'S

Background

Accurate measurements of the subcritical level is an important research topic in the development of Accelerator Driven Systems (ADS) as well as for the determination of the subcriticality level in storage pools or during loading operations in LWR's. For ADS, it is clear that an accurate absolute determination of the subcriticality level is of paramount importance, since these systems are supposed to remain subcritical at all times. The core reload of NPP's is commonly executed by adopting the subcritical approach. This procedure allows to safely predicting the critical mass based on different subcritical states of the reactor, but it doesn't allow to obtain the subcriticality value of the different subcritical states during reload. Since practice in NPP's has shown that it would be very valuable to have access to the absolute value of the subcriticality, it is desirable to obtain a measurement technique that can be used for this purpose.

Objectives

In this project, we investigated the measurement of the multiplication factor k_{eff} in subcritical conditions in the VENUS reactor using the so-called ^{252}Cf source-detector method. These measurements are the first step in the validation process of the ^{252}Cf source-detector method to be used for subcriticality determination in ADS and during core reload in NPP's.

Principal results

Among the different experimental techniques existing today for the measurement of the subcriticality, only a few are capable of giving an absolute value of the subcriticality without knowing the actual critical state. The only way sufficient information is obtained from the measurements to derive the absolute subcriticality value is by having access to the time origin of induced fission chains and by analyzing the resulting multiplication process. Two candidate methods can then be selected: one is based on a pulsed neutron generator and the other one is based on a so-called ^{252}Cf source-detector. Since in practice the use of a neutron generator is not that straightforward, we have opted to investigate the applicability of the ^{252}Cf source-detector method.

The ^{252}Cf source-detector method uses three detectors placed in the subcritical system: two “ordinary” neutron detectors (x and y) and one ^{252}Cf source-detector (figure below). The latter contains a ^{252}Cf source embedded in the detector, which introduces neutrons in the system through spontaneous fission. The starting time of each fission is measured through the detection of the fission fragments in the source-detector. The neutrons introduced in the system with each fission cause a neutron multiplication chain, which will die out because of the subcritical nature of the system. Since neutrons belonging to the same fission chain are correlated in time because they are induced by the same initial fission, there exists a time correlation between the signals in the source-detector and an ordinary neutron detector, but also between the two ordinary neutron detectors.

To obtain the correlation between the different signals, first of all the time signals of the three measurement chains are recorded. In a second step the cross (auto) power spectral densities between the different time signals are calculated:

- $S_{ss}(\omega)$: auto power spectral density of the source-detector
- $S_{sx}(\omega)$: cross power spectral density between the source-detector and detector x
- $S_{sy}(\omega)$: cross power spectral density between the source-detector and detector y
- $S_{xy}(\omega)$: cross power spectral density between the detector x and detector y

By taking the complex conjugate of the cross power spectral density of $S_{sx}(\omega)$, the following spectral ratio can be obtained:

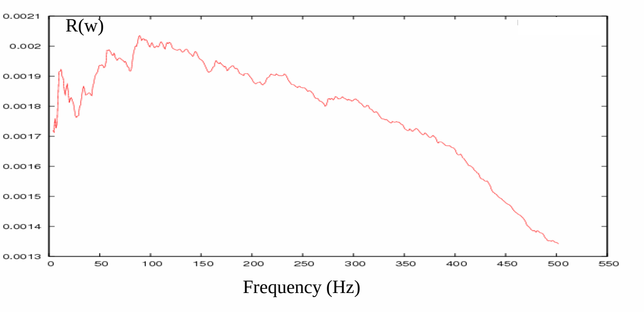
$$R(\omega) = \frac{S^*_{sx}(\omega)\cdot S_{sy}(\omega)}{S_{ss}(\omega)\cdot S_{xy}(\omega)} = \frac{\varepsilon_s \nu_0}{\dfrac{\overline{\nu(\nu-1)}}{\nu\,|\rho|} + \dfrac{\overline{\nu_0(\nu_0-1)}}{\nu_0}}$$

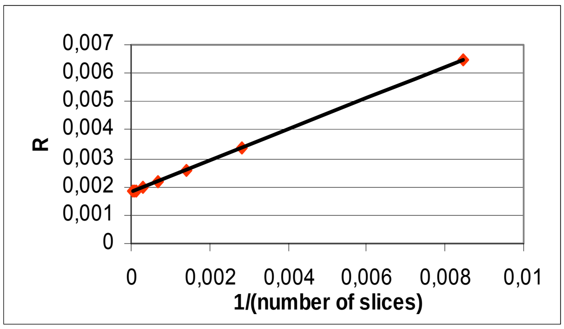
If the source-detector efficiency ε_s is known, the reactivity ρ can be determined in an absolute way, since the other parameters $\frac{\overline{\nu(\nu-1)}}{\nu}$ and $\frac{\overline{\nu_0(\nu_0-1)}}{\nu_0}$ are the reduced second order moments of the neutron multiplicity distributions which are tabulated in literature.

To investigate this californium source-detector method measurements were performed at the VENUS critical facility, a small water-moderated zero-power test reactor. The VENUS reactor consists of a fuel configuration, which can be set to any desired degree of subcriticality by variation of the water level in the reactor vessel, and is consequently very well suited for the verification of the ^{252}Cf-method.

Measurements have been made on two types of fuel configurations: a pure UO_2 core, enriched in ^{235}U, and a UO_2 core with a central MOX region. For both types of configurations, different subcritical reactivity values were reached, measured with the ^{252}Cf-method and compared with the expected values derived from experiments with reference subcritical techniques. In case of the MOX configuration, a modified formula for the spectral ratio had to be used, since some of the even Pu-isotopes act as an independent neutron source.

From the figure left below which shows the spectral ratio R(ω) as a function of frequency, one can see that this ratio is relatively constant when ω<300 and a unique value for the spectral ratio can be derived. Investigation of the method shows that this spectral ratio is a function of the number of time averages ("slices") used to determine the power spectral densities. When this number of slices goes to infinity, the correct value for the spectral ratio is obtained experimentally via a linear extrapolation as the one shown on the right figure below.





Our measurements have shown that for different reactivity levels and in both cores the reactivity obtained with the californium source-detector method is fully compatible with the reactivities obtained with reference measurement techniques except for a constant proportionality factor.

Future work

The deviation with a constant proportionality factor is due to an inaccurate calibration of the source-detector efficiency and the negligence of a spatial correction factor which is needed since the source-detector is positioned outside of the core. Both items will be further looked into in 2007.

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Main reference

P. Baeten, J. Janssens, B. Verboomen, H. Aït Abderrahim, P. D'hondt, Sub-critical measurements with the Cf source driven method in the VENUS reactor, Proceedings ICNC 2007 Conference, St-Petersburg, Russia