The Cf-252 driven noise analysis method - history and principles

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Summary

- The Cf-252 driven noise analysis is a fast and effective method of measuring the dynamic subcritical reactivity
- It has also other applications (Cf-driven die-away analysis)
- The principles and the history of the method is the subject of my first talk, which will include also some personal reminiscences and a video of an experiment
- The Cf-252 method requires a special type of source-detector combination (in short, but misleadingly) also called a "Cf-252 detector"
- The traditional device uses for such purposes has been based on an ionisation chamber
- A new, fiber-based type of a Cf-252 detector was suggested recently by undersigned
- This is the subject of the second talk

Measurement of reactivity

In most cases (except the inverse kinetic method), the subcritical reactivity is determined by measuring the prompt neutron decay constant α:

$$\boxed{\alpha = \frac{\rho - \beta}{\Lambda}} \tag{1}$$

Methods of measuring α:

- Pulsed neutron measurements with a neutron generator (in particular the area ratio/Sjöstrand method)
- Correlation based pulse counting methods (Rossi-alpha, Feynman-alpha etc.)
- The Cf-252 method

The pulsed neutron method

Decay of the pulse: $\phi(t) = \phi_0 \, e^{-\alpha \, t}$

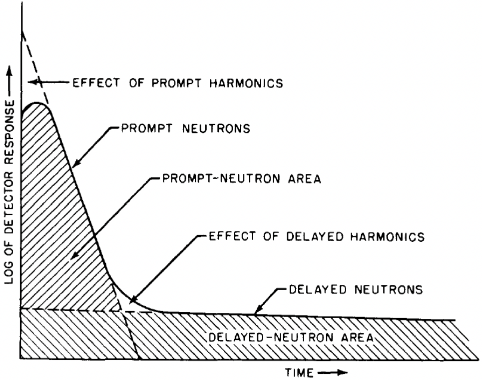

FIG. 10.6 DETECTOR RESPONSE VS TIME AFTER INJECTION OF INSTANTANEOUS NEUTRON PULSE INTO SUBCRITICAL SYSTEM.

The correlation method

Decay of the correlations: Rossi-alpha method.

The Rossi-alpha fuction $R(\tau)$ (autocovariance to mean or) is defined as

$$R(\tau)\,d\tau = \frac{C_Z(\tau)\,dt\,d\tau}{\langle Z(t,\,dt)\rangle} = \frac{\langle Z(t,dt)\,Z(t+\tau,d\tau)\rangle - \langle Z(t,\,dt)\rangle\langle Z(t+\tau,\,d\tau)\rangle}{\langle Z(t,\,dt)\rangle} \qquad (2)$$

where Z is the number of counts (random variable).

Keeping only the prompt term,

$$\boxed{R(\tau) = A\,e^{-\alpha\,\tau}} \qquad (3)$$

The Feynman-alpha (variance to mean) method is also based on the correlations, because

$$\sigma_Z^2(T) = \langle Z(T)\rangle + \int_0^T \mathrm{d}t_1 \int_0^T \mathrm{d}t_2\, C_Z(|t_1-t_2|) = \langle Z(T)\rangle + 2\int_0^T \mathrm{d}t \int_0^t \mathrm{d}\tau\;\; C_Z(\tau). \qquad (4)$$

The correlation method

Like with the pulsed neutron method, the decay of the correlations is measured between a start and a stop signal.

- Start signal: the first detection
- Stop signal: the second detection
- Disadvantage: the first detection eliminates all prospective progeny (descendant) that would have been created by the detected neutron
- Hence the method is ineffective for measuring deep subcriticalities.

The Cf-252 method

The Cf-252 method eliminates the weakness of using the detection of two neutrons from the same chain to determine the decay of the correlation.

The Cf-252 source is coated on one of the electrodes of an ionisation chamber, which detects the fission products of the spontaneous fission.

- Start signal: the detection of the fission fragments
- Stop signal: the first neutron detection (with a neutron detector)
- It is still a correlation method, since the start signals are random
- Advantage: the start signal does not eliminate any of the neutrons
- Hence the method is effective for measuring deep subcriticalities.

The Cf-252 method of J. Mihalczo

- It uses power spectra densities, which is a method based on continuous detector signals.
- Due to the fast signal processing (FFT), it is a fast method, usable at higher count rates, such as measuring the subcritical reactivity in power reactors under start-up.
- It was brought to the attention of this speaker during my very first visit to Japan in 1990, by my host Professor Kojiro Nishina.
- The Nishina lab, including Assoc. Prof. Yoshihiro Yamane, were much involved into the methodology of the Cf-252 method of measuring subcritical reactivity.


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The Cf-252 method of J. Mihalczo

It is not a correlation, but a spectral method. It uses the signals of a Cf-252 detector/source (#1), and two separate neutron detectors (#2 and #3, respectively).

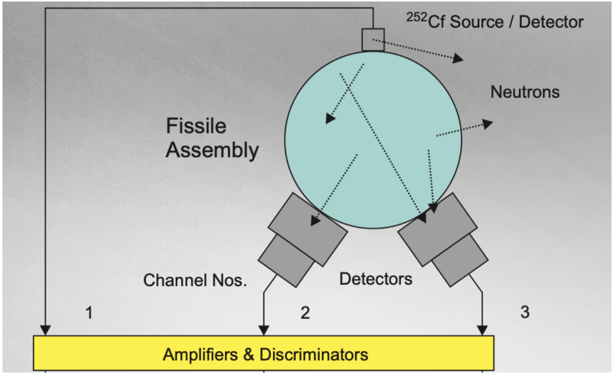

Figure 1: The layout of the Mihalczo method of measuring subcritical reactivity

The Cf-252 method of J. Mihalczo

The reactivity is extracted from a spectral ratio, i.e. from the combination of the auto- and cross spectra of some detector combination as follows:

$$R(\omega) = \frac{G_{12}^*(\omega)\, G_{13}(\omega)}{G_{11}(\omega)\, G_{23}(\omega)} = \frac{\nu_c}{\nu} \frac{I_c}{I} \frac{1}{F\, D_\nu}\, \rho \qquad (5)$$

Here

- ν_c and ν are the average number of neutrons from a Cf-252 and ^{235}U fission;
- I_c and I are the average importance of the source and fission chain neutrons;
- D_ν is the Diven factor of the fission chain neutrons (^{235}U)
- F is a factor correcting for the deviation from point kinetics.

Advantages

Within the frequency range of interest, $R(\omega)$ is approximately constant.
Advantages:

- Neither the source strength, nor the detector efficiencies appear in the expression
- Because of the fast data processing (FFT) the method is fast
- It gives the reactivity in absolute value, does not require the knowledge of β and Λ
- In the literature it is often stated as if the method is hence “calibration-free”, but in practice determination of the factors in the formula amounts to a calibration.

What next

- In the next talk the traditional Cf-252 detector will be described, and the proposal for a new type of detector/source will be presented