A Feasibility Study to Measure the subcriticality of a PWR core

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1. Introduction

For the safe and efficient operation of a subcritical reactor core, the subcriticality of the core is very important information. So far in the commercial nuclear industry, this information can only be inferred, not directly measured. Recently, Westinghouse has developed the Spatially Corrected Inverse Count Rate (SCICR) method for subcritical reactivity measurement, which can determine the negative reactivity of a subcritical core for any static subcritical condition and control rod configuration, and consequently the change in reactivity via the use of ex-core detector signal measurements and advanced subcritical core condition predictions.[1] And similar method using the digital reactivity meter coupled with the modified neutron multiplication method (NSM) was developed and applied to several PWRs in JAPAN [2,3]

But either SCICR or NSM has to measure the initial core subcriticality through other conventional techniques at the nearest critical condition to calculate the negative reactivity at any core condition

If one can measure the subcriticality of a commercial PWR core, he/she can speed up the process of approaching criticality as well as reduce the critical path time to power ascension of the core. If it is possible to measure the core subcriticality at specific condition, the technique can be also applied to measure the reactivity of spent fuel storage. But at present, although there are many methods to measure the subcriticality of various test or criticality reactors, there is no concrete and well-defined way for a subcritical PWR core because it is difficult to assess neutron source distribution accurately and to describe local neutron effect on excore detectors due to large core size.

Recently, in order to develop subcriticality measurement method for PWR, KEPRI investigated tens of method including SCICR and tested the applicability of Feynman-α technique (or variance-to-mean method) using measured source-range excore detector signals, which was estimated as the most possible technique for PWR. Actually Jun had used this method to measure the reactivity of TRIGA Mark-II reactor at 1990. [4] He had concluded that the method is the best except long computing time. This paper is going to discuss the some experimental results.

2. Methods and Results

The Feynman-α method [1] is well known and used widely in the filed of subcriticality measurement. But this technique has not been applied to commercial PWRs. In the traditional Feynman-α method, the variance-to-mean of the detector counts in a short time interval enough for neglecting precursor effect is formulated as following [5]:

$$VTMR = \frac{\sigma^2}{\mu} = \frac{\overline{\sum_{i=1}^{N} c_i^2} - \left(\overline{\sum_{i=1}^{N} c_i}\right)^2}{\overline{\sum_{i=1}^{N} c_i}} \qquad (1)$$

$$= 1 + \frac{\varepsilon \cdot \overline{\nu(\nu-1)}}{\bar{\nu}^2} \frac{1}{(\beta-\rho)^2} \left\{ 1 - \frac{1-e^{-\alpha t}}{\alpha t} \right\},$$

where α is defined as (β-ρ)/Λ, c_i the number of count in a given time interval t (or gate length), ν the average number of neutrons produced by a single fission event, ρ the reactivity to be measured, β the total delayed neutron fraction, ε detector efficiency in counts/fission, and Λ the generation time. VTMRs corresponding to different gate lengths can be calculated the count data gathered by multi channel analyzer.

An example of excore detector location is shown in Fig. 1. Fig. 2 shows the diagram how to get the useful information from the excore detector at source range. The pulses generated from excore detector are transferred to the pulse height discriminator where the gamma-ray induced pulses are discriminated. Then the log pulse integrator or scaler-timer convert pulses to voltage signals from 0V to 5V or beep sound, respectively.

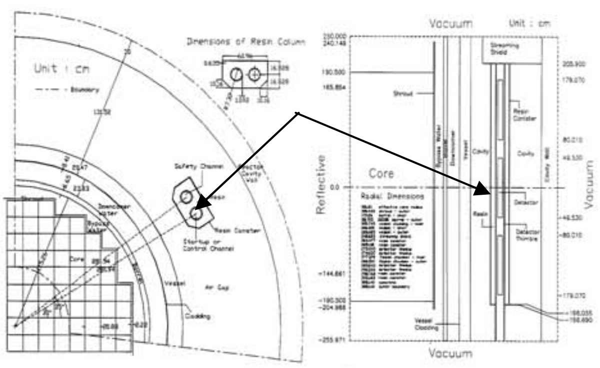

Fig. 1 Locations of source range detector in KSNP

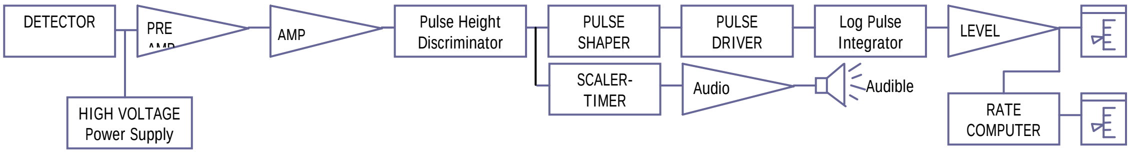

Fig. 2. The diagram for excore detector signal processing

We have gathered the pulse counts at the front of the scaler-timer at steady core condition of five startups of different PWR types including the initial core of a KSNP. During 10 min ~ 40 min the counts per 10^{-3}sec are recorded in a hard disk. Accumulated measured data has used to calculate VTMR and each result is fitted by least square method based on equation (1). The time interval is fixed as 0.001sec. Fig. 3 shows an example of pulse counts history for WH type reactor.

In four cases, we have failed to get a meaningful result. Fig. 4 shows some results of VTMR where it is impossible to get a significant alpha value fulfilling equation (1). But there is a case that presents good VTMR behavior and reasonable alpha value, i.e, reactivity compared with the design value. One can see it at Fig. 5.

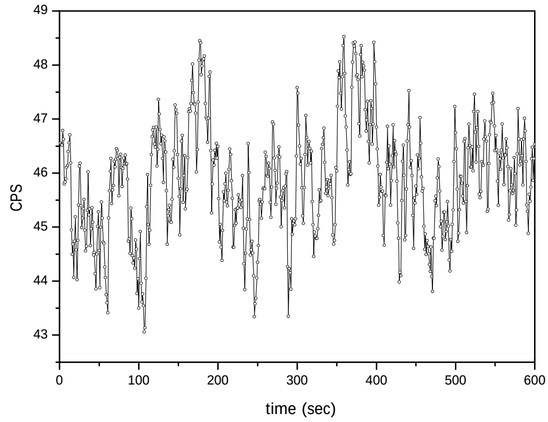

Fig 3. Measured pulse counts history in a WH reactor

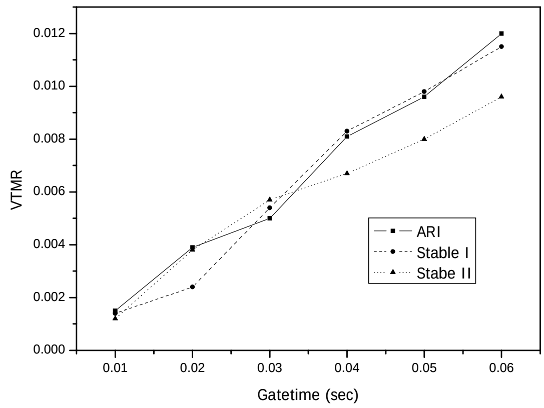

Fig. 4. An example of failed VTMR case

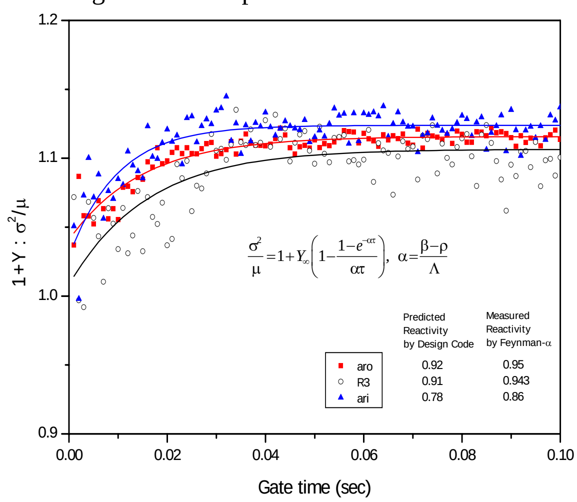

Fig. 5 VTMR variations and reactivities measured at the initial core of a KSNP

3. Conclusion

The Feynman-α method was applied to measure the subcriticality of commercial PWR cores for the first time in the world. Those tests were performed as a feasibility study to confirm whether it is possible to measure the subcriticality of a PWR core using the method or not. Although there were bad results, we concluded that if we set up more efficient data processing system and knows more details about subcritical core status, we can measure the subcriticality of the core through a simple technique.

References

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