Real Time Alpha Value Measurement with Feynman-α method Utilizing Time Series Data Acquisition on Low Enriched Uranium System

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As a part of the development of a subcriticality monitoring system, a system which has a time series data acquisition function of detector signals and a real time evaluation function of alpha value with the Feynman-alpha method was established, with which the kinetic parameter (alpha value) was measured at the STACY heterogeneous core. The Hashimoto's difference filter was implemented in the system, which enables the measurement at a critical condition. The measurement result of the new system agreed with the pulsed neutron method.

KEYWORDS: STACY, heterogeneous core, kinetic parameter, real time measurement, Feynman-alpha method, time series data

1. Introduction

As a lesson from the JCO criticality accident [1], the importance of a continuous monitoring technique of subcriticality has been recognized again.

Monitoring of the kinetic parameter alpha, which is a decay time constant of the prompt neutron, does not provide information of subcriticality directly unless the alpha of a critical condition is known. The alpha, however, could be an alternative index of subcriticality if neutronic characteristics of the target system of monitoring vary in a limited range, e.g. within the range of a thermal uranium system, and if a maximum alpha value at a critical condition of the target system is known.

The larger computation capacity which has been realized recently on a small size personal computer also gives a practical application of reactor noise theories to the subcriticality monitoring. A proto-type of the monitoring system was built in a personal computer and its function was tested in the Static Experiment Critical Facility (STACY) in the Nuclear Fuel Cycle Safety Engineering Research Facility (NUCEF), Japan Atomic Energy Research Institute.

In this report, the concept of the monitoring system is proposed and the results of the function test are presented.

2. Outline of the Monitoring System

2.1 Monitoring of Alpha Value

Counting signals of neutrons or gamma-rays from a detector located around the system containing fissile materials are analyzed by a computer with a reactor noise theory and an alpha value of the system is periodically evaluated in real time. In addition to the monitoring, the system should be simulated considering the process operating conditions or fissile material

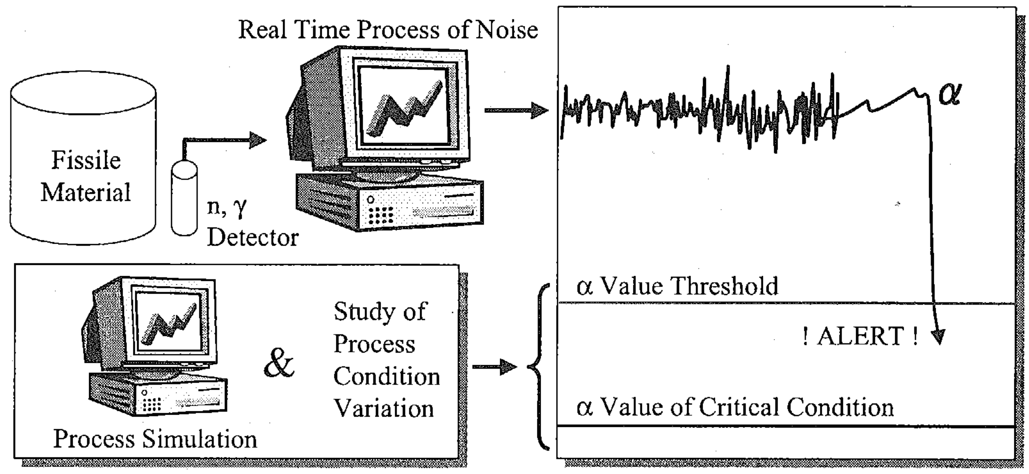

Fig.1 Concept of the Monitoring System

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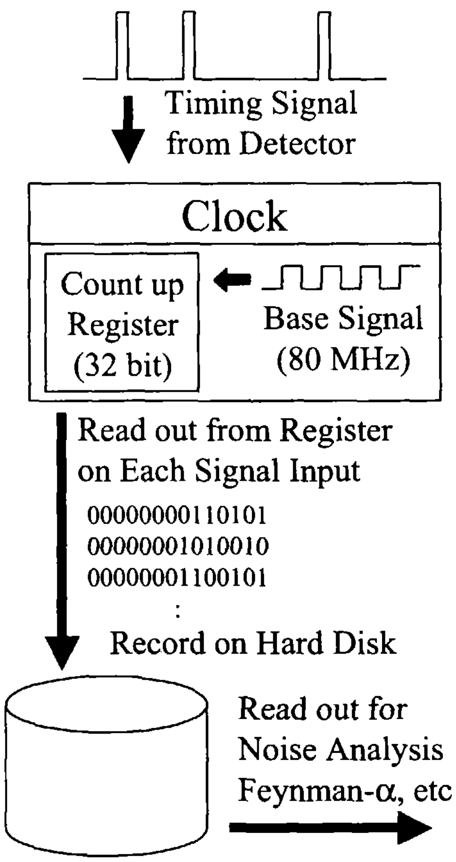

Fig.2 Time Series Data Acquisition

conditions to estimate an alpha value in a critical condition and to establish a threshold to detect the anomaly when the system is still subcritical. The alpha value generally becomes smaller if the system approaches a critical condition. The threshold must be a larger value than in the critical condition and an alert to shutdown the operation should be announced when the monitored alpha value becomes smaller than the threshold. Figure 1 summarizes the concept.

2.2 Time Series Data Acquisition

A time series data acquisition, whose input is timing signals coming from a detector, looks up an internal clock driven by a base signal of 80 MHz and records a time on each signal input. The bit-length of the clock is 32 bit and its roll over time is 53.7 sec. Recorded time series data could be provided universally for various reactor noise analysis methods such as the Feynman-alpha method, the Rossi-alpha method and so on, which are the time domain noise analyses. The frequency domain analysis is also available utilizing the time series data since the data can be easily converted with the Fourier transformation. Figure 2 shows a block diagram of the data acquisition.

2.3 Feynman-Alpha Method with the Difference Filter

For the Feynman-alpha method [2], the time series data is interpreted into a series of count rate data N_i of a time gate width τ (s). The original method evaluates the ratio V of a variance of N_i to a mean of N_i which is a function of τ. The function is expressed as

$$V(\tau)=\frac{\mathrm{Var}(N_i)}{\overline{N_i}}=1+Y_\infty\left(1-\frac{1-e^{-\alpha\tau}}{\alpha\tau}\right), \qquad (1)$$

where α is the decay time constant of the prompt neutron and Y_∞ is the saturation value for a larger gate width τ. This evaluation fits to the measurement where a mean of N_i is constant over a time duration. On the contrary, it is not available for the measurement of a very shallow subcritical condition or a critical condition when a mean of N_i varies over time, where the ratio V diverges.

A difference filter is effective to suppress the divergence. Modification of the Feynman-alpha method with the filter [3] enables the measurement of an alpha value of the system where a neutron flux varies over time. If the 1st order difference filter is applied, the modified method evaluates the ratio of a variance of $(N_i - N_{i-1})$ to a mean of N_i which is also a function of τ expressed as

$$\begin{aligned}V(\tau)&=\frac{\mathrm{Var}(N_i-N_{i-1})}{\overline{N_i}}\\&=2+2\,Y_\infty\left(1-\frac{1.5-2e^{-\alpha\tau}+0.5e^{-2\alpha\tau}}{\alpha\tau}\right)\end{aligned} \qquad (2)$$

The 2nd order filter can be also utilized by evaluating the ratio of a variance of $(N_i - 1/2N_{i-1} - 1/2N_{i+1})$ to a mean of N_i which is written as follows, which suppresses slow change of neutron flux more than the 1st order filter,

$$\begin{aligned}V(\tau)&=\frac{\mathrm{Var}(N_i-1/2N_{i-1}-1/2N_{i+1})}{\overline{N_i}}\\&=1.5+1.5\,Y_\infty\left(1-\frac{5/3-5/2\,e^{-\alpha\tau}+e^{-2\alpha\tau}-1/6\,e^{-3\alpha\tau}}{\alpha\tau}\right)\end{aligned} \qquad (3)$$

3. Experimental

3.1 Measurement System

The data acquisition and the analysis system has been built on an AT compatible personal computer. The detector signals are fed into the timing I/O card of National Instruments set on the PCI bus and time series data was transferred and recorded on the hard disk, continuously. Figure 3 shows a block diagram of the measurement system. The data acquisition is controlled by a software coded on the LabView™. Inputs of 2 channels are acceptable and could be recorded separately but based on the same clock. The data on the hard disk was read simultaneously by the analysis software, where the Feynman-alpha method was implemented on Visual Basic® .NET. Calculation of the ratio V of variance/mean as a function of a

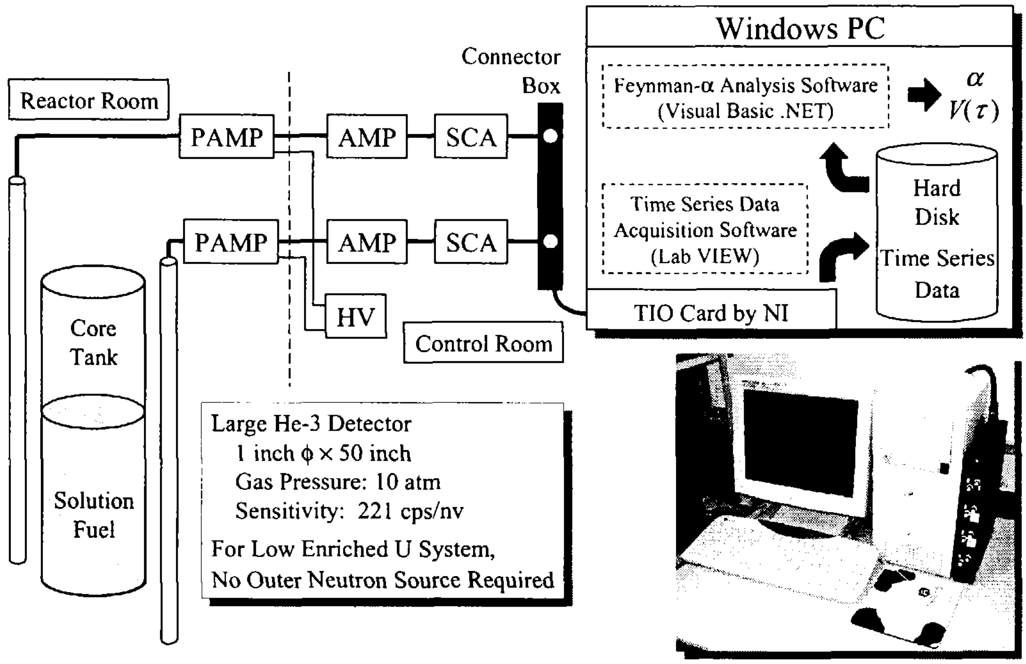

Fig.3 Measurement System

time gate width τ, and evaluation of alpha value by a least-square fitting are conducted in real time. The 1st order and the 2nd order difference filters are implemented in the analysis system.

Uncertainty reduction of the alpha value evaluation or reduction of measurement time is attained by high sensitivity of a detector. For the measurement system, a large size He-3 detector, whose size is 1 inch diameter and 50 inch length, has been employed. Its sensitivity is 221 cps/nv, with which a spontaneous fission of ^{238}U in a low enriched uranium can be treated as an outer neutron source of enough strength. Electronics instrumentation for the detector consists of very conventional modules such as a pre-amplifier, an amplifier, a single channel analyzer and so on.

3.2 Core Configuration

The measurement with the new system was conducted for the heterogeneous core of STACY [4, 5] which consisted of fuel pins of uranium dioxide and uranyl nitrate solution which are indicated in Table 1. [6] Each fuel pin contains uranium dioxide pellets whose ^{235}U enrichment is 5%. The outer diameters of a pellet and a Zircaloy-4 sheath are 8.2 mm and 9.5 mm, respectively. In the core tank of about 60 cm diameter and 150 cm height, 221 fuel pins were arrayed in a square lattice of a 2.1 cm pitch as shown in Figure 4. A uranyl nitrate solution whose ^{235}U enrichment and uranium concentration are 6% and 150 gU/L was fed into the core tank and became critical at a solution level of 52 cm with no reflector.

Table 1 Core Configuration

Core Tank (Stainless Steel)	
Diameter	~ 60 cm
Height	~ 150 cm
Fuel Pins (Uranium Dioxide)	
^{235}U Enrichment	5%
Outer Diameter of Pellet	8.2 mm
Outer Diameter of Zircaloy-4 Sheath	9.5 mm
Number of Pins	221
Array Pitch	2.1 cm
Solution Fuel (Uranyl Nitrate Solution)	
^{235}U Enrichment	6%
Uranium Concentration	~ 150 gU/L
Critical Solution Level	~ 52 cm

4. Result

4.1 Subcritical Measurement

A series of measurements with the new system were conducted for several subcritical solution levels. The reactivity effect of solution level change had been calibrated [6] and subcriticalities for the solution levels were known as 0.21\$, 0.52\$, 1.07\$, and 2.05\$. Figure 5. shows the measurement results of variance/mean ratios with the 1st order filter and alpha value evaluations by a least square fitting. For a shallower subcriticality, a larger variance/mean ratio was observed which indicates a higher correlation of neutron detections due to a neutron multiplication in the system. It also leads to a smaller alpha value. Evaluated alpha values are 213±1 s^{-1}, 238±1 s^{-1}, 322±1 s^{-1} and 463±3 s^{-1}, respectively. The relation between subcriticalities and measured alpha values is extrapolated to the critical condition and a β/Λ value was estimated as 166.5±2.0 s^{-1} as shown in Figure 6.

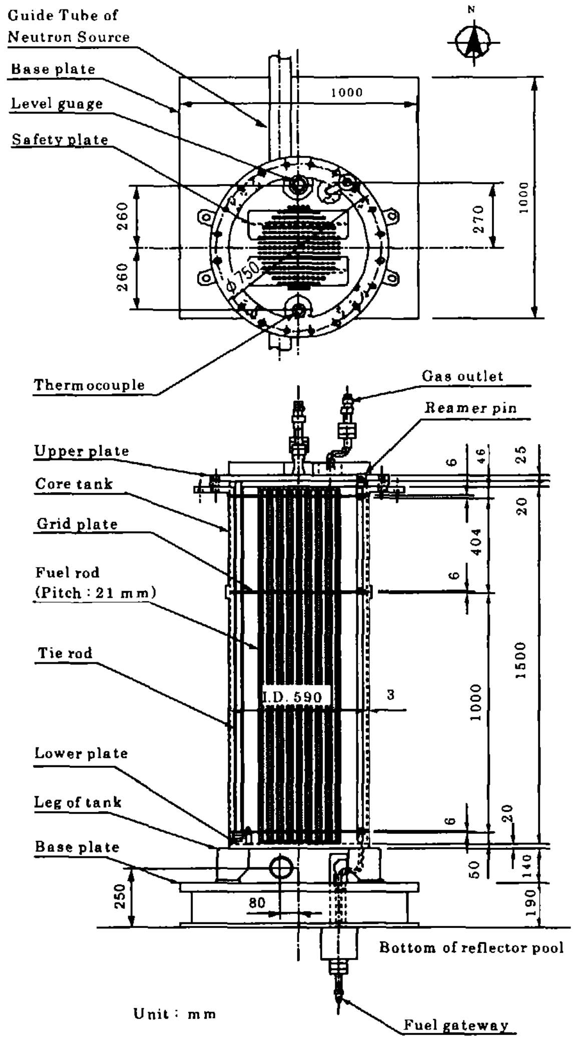

Fig.4 Heterogeneous Core of STACY

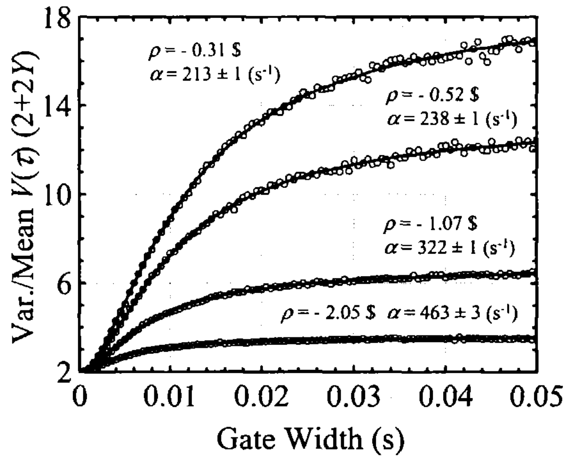

Fig.5 Result of Subcritical Measurement

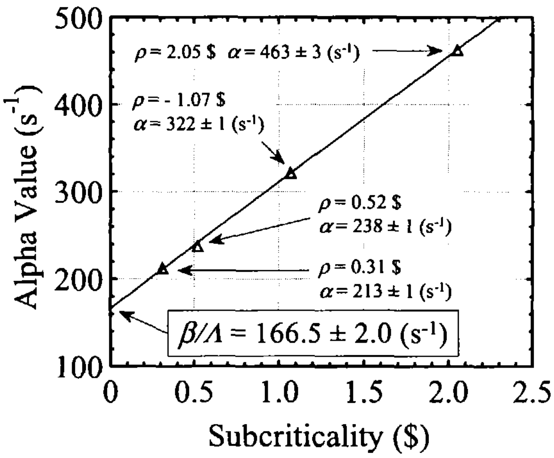

Fig.6 Evaluation of β/Λ Value based on Subcritical Measurement

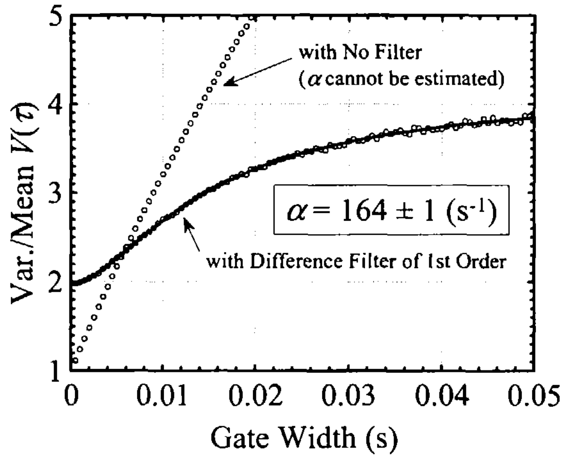

Fig.7 Result of Critical Measurement

4.2 Critical Measurement

At the critical condition, a measurement was also conducted and time series data was recorded. The Feynman-alpha analysis was performed utilizing the same time series data with and without the difference filter. Figure 7 shows the result of analysis with no filter, where the variance/mean ratio diverged for the larger gate width and an alpha value cannot be evaluated. The figure also clearly shows the effect of difference filter suppressing the divergence which enables an alpha value evaluation. The measurement with the 1st order filter gave 164±1 s^{-1} as an alpha in the critical condition.

4.3 Pulsed Neutron Source Method

The alpha value measurement by the pulse neutron source (PNS) method was conducted for several known subcritical conditions. The relations between subcriticalities and alpha values measured by both methods agree well to each other. The β/Λ value at the critical condition derived from the PNS method is 164.2±0.6 s^{-1}.

4.4 Comparison

Comparison of β/Λ values between

- the derivation from subcritical alpha values measured by the new system: 166.5±2.0 s^{-1},
- the direct measurement in a critical condition by the new system: 164±1 s^{-1} and
- the derivation from subcritical alpha values by the PNS method: 164.2±0.6 s^{-1}

shows good agreement within uncertainties of measurements.

5. Conclusion

Functions of a time series data acquisition and a reactor noise analysis are integrated on a personal computer and the measurement system which is able to measure the alpha value in real time has been established. The difference filter is implemented in the system, with which the alpha value measurement of a critical condition can be performed. By employing a large size He-3 counter, an outer neutron source is not necessary at the measurement for a subcritical system of low enriched uranium. The results of measurement with the new system for the STACY heterogeneous core were compared with the results of the PNS method and the new system has been validated.

The applicability of the new system should be tested for a deeper subcritical condition. The time response of the new system when a reactivity changes over time should be also studied.

Acknowledgements

The authors wish to thank the STACY operators for their effort and cooperation to perform the measurement.

This paper is a part of the result of research activity performed under the contract with the Ministry of Education, Culture, Sports, Science and Technology of Japan.

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