DIGITAL SIGNAL PROCESSING OF PULSE COUNTING AND MSV MEASUREMENT FOR IN-CORE INSTRUMENTATION

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A digital signal processing technique for pulse counting and mean-square-voltage (MSV) measurement were developed for start-up range neutron monitor (SRNM) used in BWR plants. The output pulse of fission detector is sampled at 40MHz. From these sampled data, digital signal processing directly performs pulse counting and MSV measurement. This processing has the following two key features: (1) digital pulse counting technique, allowing rejection of the error counts induced by external noises, and (2) digital over-sampling technique, allowing MSV measurement to cover the ranges of the measurement required for SRNM. A real-time processing prototype apparatus was manufactured and tested at Toshiba Training Reactor (TTR). This apparatus can demonstrate a successful performance of the digital signal processing for SRNM and make it possible to accurately count only the detector output.

Introduction

The neutron monitoring system in the BWR plants consists of two subsystems as shown in Figure 1. One is the Start-up Range Neutron Monitor (SRNM) and the other is the Local Power Range Monitor (LPRM).

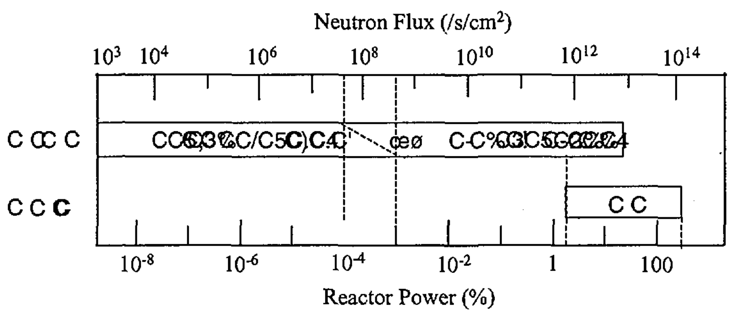


Figure 1.The measurement range of the neutron monitoring system

As shown, these two subsystems can cover more than 10 decades of reactor power range(10^{-9}% ' 100%). SRNM system can monitor start-up ranges(10^{-9}% ' 10%)[Ref.1]. SRNM counts the number of output pulses from an SRNM detector (pulse counting mode) in low reactor power ranges(10^{-9}% ‘ 10^{-4}%) and measures the fluctuation from an SRNM detector (MSV measurement or Campbell method) in intermediate reactor power ranges(10^{-5}% ‘ 10%).

SRNM system consists of an in-core fixed SRNM detector, and an analog pre-amplifier, a drawer unit including a pulse counting apparatus and an MSV measurement apparatus. The pulse counting apparatus consists of a pulse height comparator comparing the pulse height of the detector output with a preset discrimination level and counting the number of the detector output pulses having heights higher than the preset discrimination level. On the other hand, the MSV measurement apparatus consists of analog band pass filters and RMS operators. RMS operators calculate mean square root of the filter outputs.

It is necessary for the reliable SRNM operation that the signal cable is routed separately from all power-carrying cables and electrically shielded sufficiently to reduce external noises because the SRNM signal cable is very long (about 100m) and the SRNM signal level is low (about some ten microvolts). To prevent erroneous measurement due to the external noises, there is a method of using not only pulse heights but also pulse waveforms since the waveforms of erroneous pulses, in most cases, are different from those of signal pulses. Further, since a detector output pulse changes due to the leakage of gas, which is sealed in the detector, or due to the discharge between electrodes, it is possible to detect these abnormal states by monitoring waveforms.

In recent years, interest in the use of digital signal processing has greatly increased because it is possible to simplify the system and execute complicated processing. In particular, digital processing with finite impulse response (FIR) filter has a limited transient response time and distortion of a wave is smaller than that in the case of analog processing.

For former erroneous measurement problems induced by external noises, a solution was developed, namely a new digital signal processing technique for pulse counting and MSV measurement. This paper presents the algorithm of digital pulse counting and reports the performance of the real-time processing apparatus using these techniques.

Digital Pulse Counting algorithm

In analog signal processing, most of the unwanted pulses arising from alpha and gamma interactions with the detector may be eliminated by pulse amplitude discrimination circuits consisting of an analog comparator. This analog counting system counts erroneous pulses which are higher than the discrimination level, nevertheless, whose waveforms are different from those of signal pulses because only pulse height information is used. For digital pulse counting, both the pulse width information and the pulse height information are used, and so it is possible to accurately discriminate only the detector output pulses from among those including other noise signals of different pulse widths.

This digital pulse counting algorithm used in the prototype apparatus is described, referring to Figure 2. Figure 2 is a view illustrating the relationship between the waveform of an SRNM detector output pulse and a sampling interval. Reference symbol S(k) in Figure 2 denotes k-th sampling value out of a plurality of sampling values forming the first sampling data, and S(k+1) denotes the next sampling value. The sampling interval of 25ns is selected. If the sampling interval is shorter, more waveform information can be extracted. But we selected this sampling interval, which is thought to be the maximum time required to discriminate the pulse, in order to carry out the processing in a real-time manner.

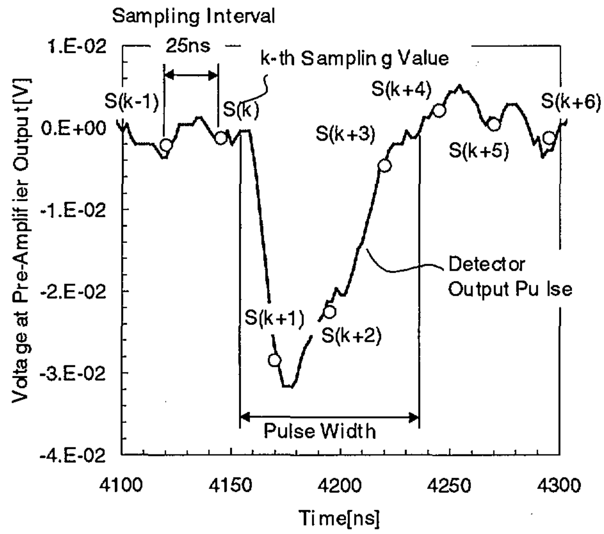


Figure 2. The relationship between the SRNM detector output pulse and sampling

The following operation obtains k-th Out(k) for each sampling interval using the k-th sampling value S(k), three sampling values S(k-3), S(k-2) and S(k-1) before the k-th sampling value:

$$Out(k)=S(k-3)-S(k-2)-S(k-1)+S(k)$$

And the number of Out(k) higher than a preset discrimination level is counted after the lapse of count dead time (about 80ns), whereby it was confirmed that only the detector output pulses can be selected and counted.

In this way, if waveform selection algorithms -- in which a plurality of arithmetic formulas for pulse selection are set based on the characteristics of the pulse waveforms and a pulse is determined as a detector output pulse if the respective operation values satisfy the condition as a pulse -- are adopted at the same time, more accurate pulse counting can be conducted.

System Description

The configuration of the digital processing apparatus is shown in Figure 3, compared to conventional analog signal processing. As shown, this digital apparatus consists of three components: an A/D converter, a programmable logic device (PLD) with 40MHz clock, and a digital signal processor (DSP) with 80MIPS performance.

The signals from an SRNM detector are fed to an analog amplifier, which amplifies and limits the frequency band of the signals, acting as an anti-aliasing filter. The A/D converter samples analog signals from analog pre-amplifier at 40MHz.

The PLD performs the digital pulse counting and sum operation. The sum operation is addition of forty sampling data from A/D converter to obtain data sum at 1MHz. This sum operation can enhance the measurement accuracy. For example the sum of two eight-bit data has accuracy of nine bits. By using this over-sampling technique, commercial A/D converters common to the pulse counting and the MSV measurement can be adopted.

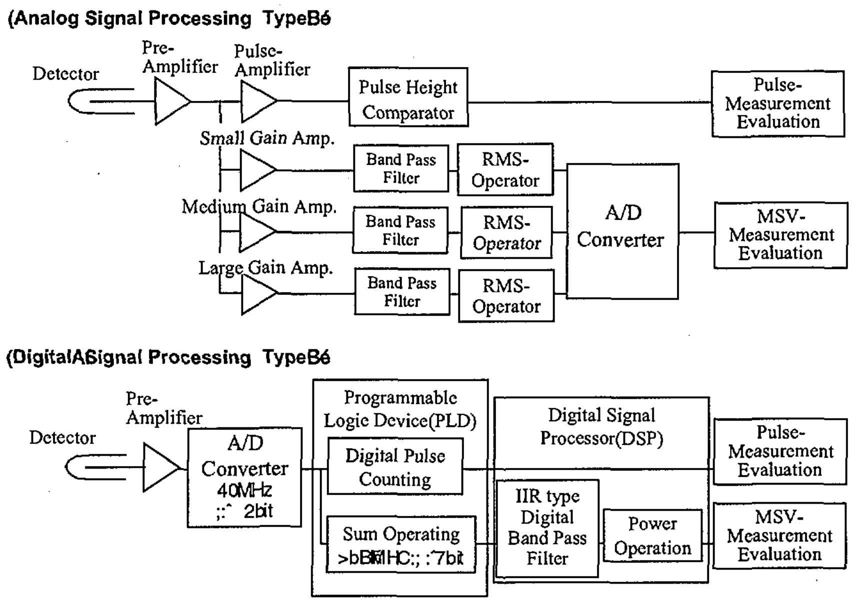


Figure 3. Functional block diagram of the digital signal processing prototype apparatus compared with the conventional analog processing apparatus

The range of MSV measurement by prototype apparatus, which is operated by one linear amplifier, is shown in Figure 4. It is confirmed that this digital processing can cover the entire range of MSV measurement required for SRNM (about 6 decades), whereas two or more linear amplifiers are required in the case of using conventional equipment.

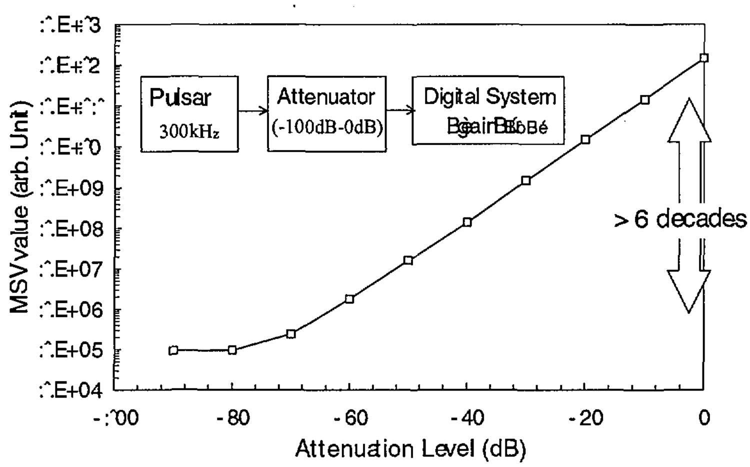


Figure 4. The range of MSV measurement against sine wave input

The data sum is sent to a digital signal processor (DSP). The DSP performs band restrictions, second power operation and data averaging. The band for power operation determines the output cycle of this sum operation, a cycle of 1MHz. Since power operation is normally conducted in a frequency band of 100kHz to 400kHz for the present SRNM monitor, sampling having a cycle of about twice (1MHz in this apparatus) as long as the maximum frequency as a band-pass filter is required.

The frequency response of the band pass filter used in the prototype apparatus is shown in Figure 5. The characteristics of frequency lower than 500kHz depend on the characteristics of 4th order infinite impulse response (IIR) digital filter. This filter consists of two digital filters:(1) 2nd order butterworth type high pass filter, and (2) 2nd order elliptic type band pass filter designed by bilinear transformation method. The characteristics of frequency higher than 500kHz depend on the characteristic of the sum operation. The aliasing part of the IIR filter is decreased by this sum operation. As shown in Figure 5, the calculated frequency characteristic is consistent with the measured frequency characteristic. So, the frequency characteristic can be easily modified by the digital filter design only.

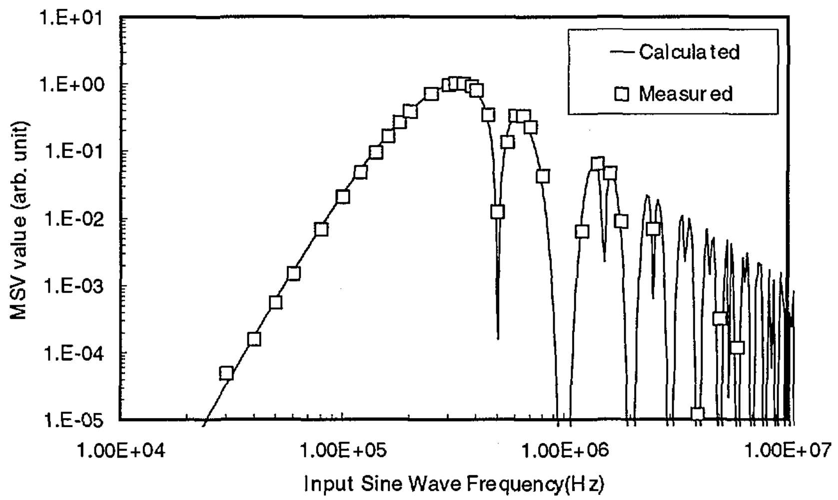
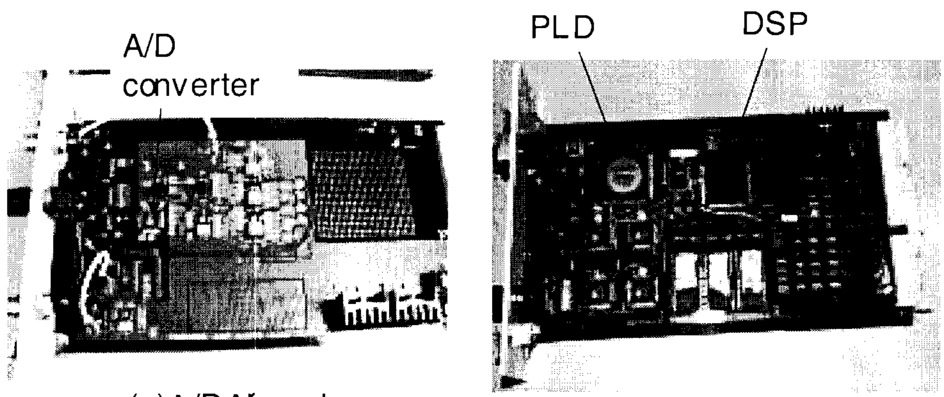


Figure 5. Frequency response characteristics of MSV measurement

The power operation conducts integral processing after square operation. A band for the integral processing is determined to be about 50Hz or less based on the time response characteristics in MSV measurement. It was confirmed to be sufficient for averaging operation in a cycle twice as long as a required frequency, i.e., a cycle of 100Hz. It is possible to reduce operation quantity in the MSV measurement.

The data of counting and MSV measurement stored in the two-port RAM are read by a personal computer with a digital I/O interface.

As stated above, the digital signal processing apparatus can be greatly simplified compared with the conventional analog signal processing equipment for SRNM. Figure 6 is a view of two electronic boards of the prototype apparatus.



(a)A/DAboard (b)PLD/D SPAboard

Figure 6. The view of electronic boards of the prototype apparatus

Performance Test

The noise reduction test and the reactor test were performed to confirm the performance of the neutron detection with noise reduction. The evaluation items for SRNM are shown in Table 1. The target performance in Table 1 is almost equivalent to the performance of the conventional SRNM.

Table 1. Evaluation Items for the neutron detection performance

Evaluation Item		Target Performance
Linearity	Counting	Upper Limit(10%Error): 2 ~ 10^6(/s)
	MSV	Crossover with Counting: 1.0dec.
		Range: 6 decades
Pulse discrimination level		¿ noise level

The configuration for noise reduction test is shown in Figure 7. A power-carrying cable between the motor and the power drive inverter was used for noise source. The signal cable of the SRNM was routed near the power carrying cable. The SRNM system consisted of a pre-amplifier, a digital signal processing prototype apparatus, a personal computer obtaining the measured data from the digital signal processing apparatus and a simulated SRNM detector.

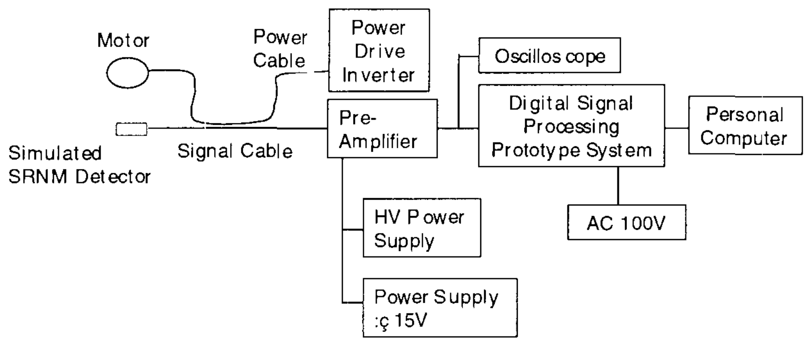
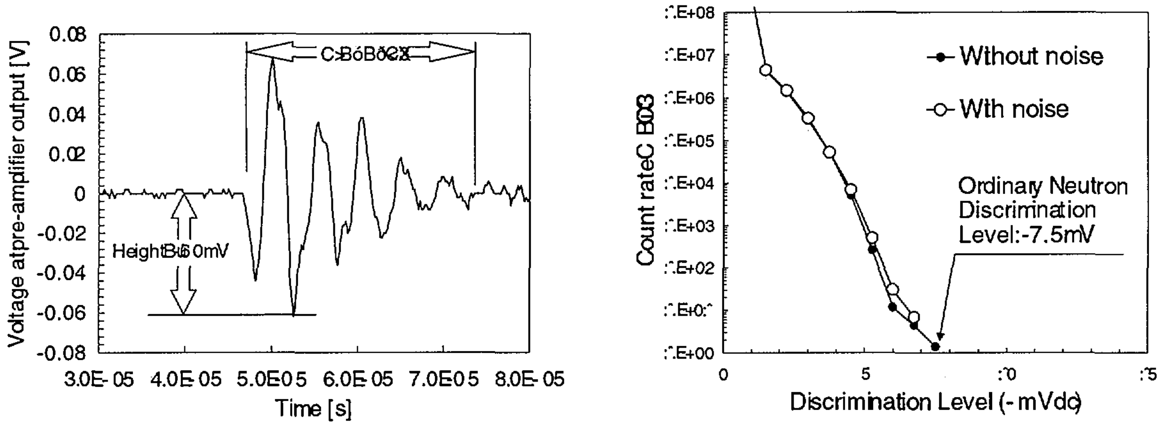


Figure 7 Test configuration for noise reduction test

The waveform of the noise induced by the inverter is shown in Figure 8(a). This pulse height is about –70mV, which is higher than the neutron discrimination level (about 7.5mV). This noise is counted by the conventional analog counting.



(a) noise signal (b)integral pulse height distribution

Figure 8. Integral pulse height distribution with and without external noise

The integral pulse height distribution is shown in Figure 8(b) with and without external noise. It is confirmed the integral pulse height distribution is not changed whether the noise is induced to the apparatus or not.

The reactor test configuration at TTR is shown in Figure 9. The SRNM detector was inserted into a watertight tube, which extended into the reactor core. The reactor power was determined by using the reactor instrumentation.

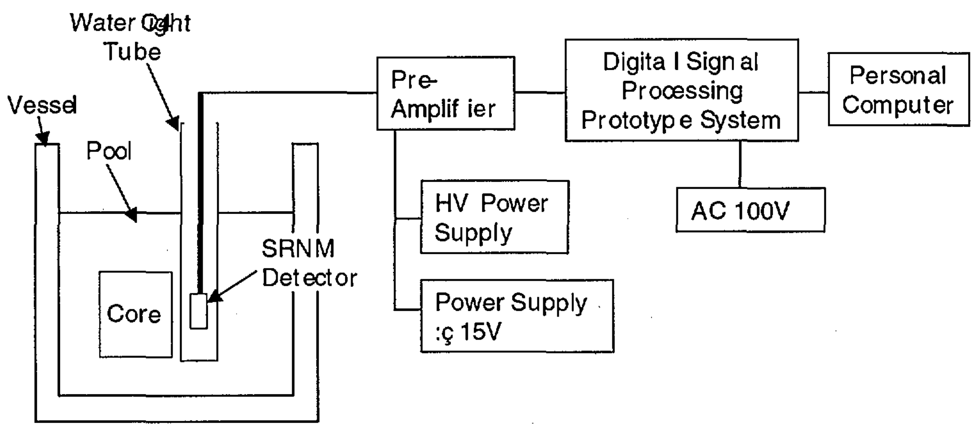


Figure 9. Test Configurations at TTR

Before reactor startup and at different reactor power, an integral pulse height distribution was measured to determine the proper discrimination level. The results of this measurement are shown in Figure 10. The discrimination level was set at -9.5mV for the test, which is slightly larger than original neutron discrimination level: -7.5mV. But the neutron pulses from detector almost can be counted, and ¿ noise is discriminated at this discrimination level.

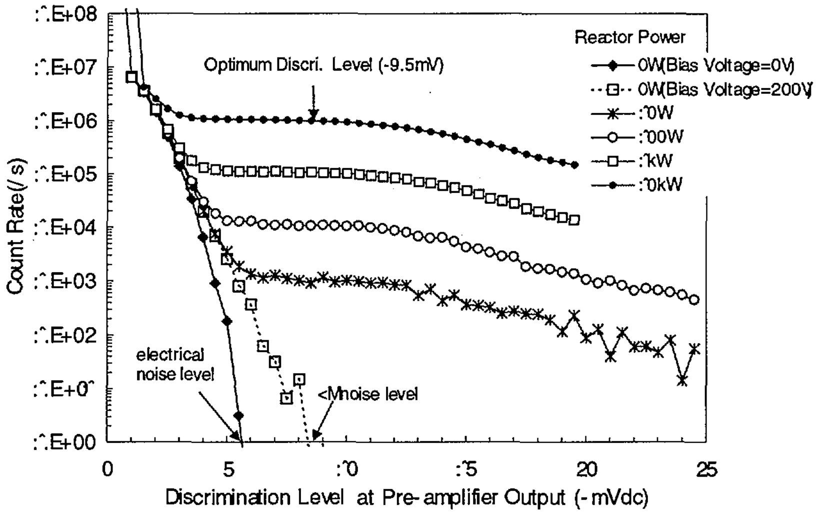


Figure 10. Integral pulse height distribution at several reactor powers

The Linearity & crossover characteristics between pulse counting and MSV measurement are shown in Figure 11. The linearity of the pulse counting could be expected to be linear to 2E6 (/s). Its range is almost the same range as that of the analog apparatus. The lower limit of MSV measurement is equal to that of the analog apparatus. This prototype apparatus has a sufficient crossover region over one decade.

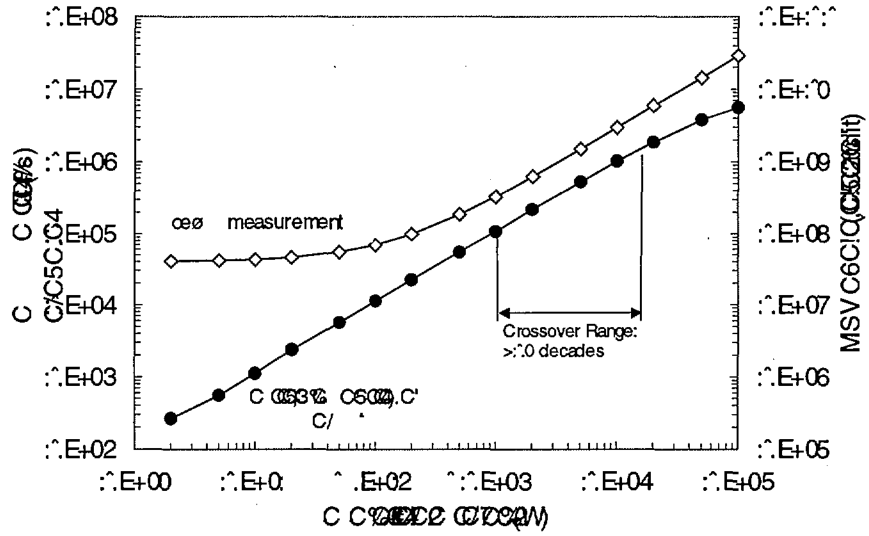


Figure 11. The crossover characteristics between pulse counting and MSV measurement

Conclusions

An algorithm, which performs pulse counting and mean-square-voltage measurement by real-time digital operation, was developed. By using a PLD and a DSP, the compact system, which performs the digital pulse counting and MSV measurement in a real-time manner, was manufactured. Since the method of digitally measuring the pulse is used and a logic for discriminating a noise component is provided, it is possible to perform more accurate pulse counting by comparing the measurement result of the conventional analog measurement with the digital measurement logic used in the prototype real-time processing apparatus. The reactor test demonstrated that the digital signal processing apparatus would perform its function as required for SRNM.

Reference

[1] Y.Endo et al., "A Counting-Campbelling Neutron Measurement System and Its Experimental Results By test Reactor", IEEE Transactions on Nuclear Science, vol.29, No.1, 1982