Proceeding of the Korean Nuclear Society Autumn Meeting
Seoul, Korea, October 1998

Application of an on-line data acquisition system for the research reactor parameter measurements

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Abstract

An on-line experimental system using a personal computer (PC) was developed at TRIGA reactors in Korea to measure various reactor parameters, from August 1990 to July 1992, as a part of IAEA Coordinated Research Project (CRP) on PC applications to research reactors. This system has been successfully applied to the commissioning test of 30 MW HANARO in 1995 and for its subsequent experiments for safe and efficient operation.

For the HANARO commissioning test, it was effectively used in criticality measurement, reactivity measurement, noise analyses, and trend analyses for various signals. For the routine operation, it has been used as an operator aid for safe startup, absorber rod worth measurement, reactor diagnosis, and trend recording of interested signals. It provides a convenient feature of data handling for the in-depth study on the actual phenomena, comparisons among analysis methods, development of new analysis methods, etc.

This paper shows how a conventional PC based data acquisition system is effectively used for reactor physics experiments as well as an operator aid in reactor operations.

Introduction

In 1984, the basic research on the use of PC for research reactor physics experiments began at TRIGA reactors in Korea. An IAEA training course on research reactors motivated this work and the other subsequent courses contributed to the idea exchange. In the late 1980's, the application of PC as a reactivity meter and as a tool for time domain neutron noise analyses, was accomplished[1,2,3]. From August 1990 to July 1992, the work was extended by an IAEA CRP on 'Application of Personal Computers to Enhance Operation and Management of Research Reactors'. A system was developed covering multiple input and output (MIO), multichannel digital reactivity meter, reactor noise analyses, control rod drop time measurement and power calibration of TRIGA reactors[4,5].

The system was tuned for the nuclear commissioning test of 30 MW multipurpose research reactor, HANARO, and used from the initial criticality approach in February 1995. It was a very useful tool for the in-depth study of noise analyses and reactivity measurement. Various methods of noise analysis were tested to determine the fission power at the micro-watt range and the ratio of effective delayed neutron fraction to neutron generation time. Various reactivity parameters were measured by the digital reactivity meter, effects of various system operation to parameters were measured by the digital reactivity meter, effects of various system operation to neutron noise were analysed by real time fast Fourier transformation, and trends of multiple signals during transient tests such as electrical power failure were recorded by the MIO.

For the routine operation, the reactivity meter helps the operator for safe startup and absorber rod worth measurement, the FFT displays frequency spectra of neutron signals for the operator to detect system malfunction in early stage, and the MIO is used for trend recording of interested signals. After the reactor core is highly activated, the reactivity measuring experiment encounters difficulty due to very intense photoneutron source in the heavy water reflector. The program of reactivity meter was modified to include the capability either to determine the neutron source or to directly determine reactivity with unknown neutron source[6].

In the following sections, the configuration of data acquisition system and some applications in HANARO using this system are described.

System configuration

One of the commercial multifunction I/O boards to be plugged into IBM PC slot is chosen. A board provides 16 single ended or 8 differential multiplexed analog inputs with programmable gain amplifier, two analog outputs, 8 digital I/Os, and two timer/counter channels. Three boards are used simultaneously in a PC, by which up to three times of I/O channels mentioned above can be obtained. Different signal conditioners are used depending on detector types. Field detectors could be neutron ion chambers, thermocouples, resistance temperature detectors, neutron counters, relays, etc.

PASCAL is chosen for programming language considering less difficulty in readability than others because programme modification is very rare once the system is working. Programmes are made for each specific experiment except the MIO.

The MIO is a general purpose programme to monitor various signals. It displays many I/O values simultaneously on the screen. It works like many digital meters and counters are gathered in a wide screen. In addition, it shows the data history, the data can be saved continuously or selectively, and the counting system has features of dead time correction and no dwell time.

The digital reactivity meter reads neutron signal variations, filters random fluctuation of signals by software, calculates reactivity values for each channel by inverse point kinetics, and draws neutron signals and reactivity values. It covers a full range of detector signals which is about six decades in a typical compensated ion chamber[7]. It can be used to determine the neutron source and gamma effects, neutron source and gamma compensated reactivity when those are known, or actual reactivity directly when those are unknown[6].

The multi-input multichannel scaler (MCS) is an optimized programme for reactor noise analyses using neutron counters. It scales pulse trains from multiple counters by software. Since the number of channels can be extended as far as the PC main memory permits, virtually continuous scaling is possible. Though its scaling speed is limited for continuous scaling by the PC architecture - about 0.15 ms when an IBM 486 is used, it is fast enough for thermal reactor noise analyses.

The fast Fourier transformer (FFT) displays frequency domain spectra in real time. It is to measure reactor transfer function or for reactor diagnosis during routine operations.

A programme for graphic display of multiple signals with fast sampling speed, is also made for the absorber rod drop time measurement.

Applications in HANARO

The system has been used for various experiments in HANARO as explained in the section of introduction. More details for some cases are presented in this section.

Fig. 1 shows the inverse multiplication curve for the initial criticality approach of HANARO. Two BF_3 and fission counters each, were used as neutron detectors, and their count rates were measured by the MIO. All guests in the control room invited to observe the initial criticality recognized criticality because the frequency of audible sound generated by the computer increased steadily.

Neutron pulse trains are scaled by the MCS and the data are analysed by different methods of variance to mean ratio (VTMR), auto- and cross-correlation, and auto- and cross-power spectral density (APSD or CPSD), to determine fission power and the ratio of effective delayed neutron fraction to neutron generation time (β/Λ). Acute determination of fission power for the clean core was very important to guarantee sufficiently low fuel radioactivity for direct safe handling of fuel assemblies after long term extensive experiments. The measured fission power at subcritical status was less than 40 μW and the experimental neutron detectors were calibrated. It agreed very well when the fission power was measured at above 10 kW by thermal and fast neutron flux distribution, using activation wires. Fig. 2 is an example of VTMR. The discrepancy between the fitted and measured data at the right hand side of this figure, is because an approximated equation for the delayed neutron terms is used and that part is not included in the actual fitting. Fig. 3 is the trend of a prompt neutron decay constant (Rossi-α) depending on subcriticality, which shows how the β/Λ is determined for a critical core. From the theoretical point of view, α versus reactivity should be very close to a straight line, but the experimental result is curved and agrees very well with the result from Monte Carlo simulations. Some other unresolved questions were raised, as well, to the basic theory of neutron noise.

APSD and CPSD are measured by the FFT using two compensated ion chambers, to determine the reactor neutron transfer functions at various conditions such as reflector pump on or off, primary and/or secondary cooling pump on or off, various reactor powers, etc. During power operation, APSDs are displayed to help the operator judge if any unusual noise occurs. The unusual neutron noise is an indicator of a possible abnormal situation in the reactor, similar to the unusual noise of an automobile. CPSD is not displayed because it is simply very close to the average of two APSDs. Fig. 4 is an example of APSD during normal operation.

An example of neutron source and gamma compensated reactivity measurement by the reactivity meter, is depicted in Fig. 5. It is the case of when shut off rods drop at a critical status and the heavy water reflector emits lots of photoneutrons. It is easily found that while the uncompensated reactivity is far from the actual reactivity and varies as time elapses, the reactivity directly determined and believed to be close to the actual reactivity is constant from a few seconds after the end of the rod drop. The compensated reactivity in this figure means the neutron source is compensated by the values measured near critical conditions. The difference between two detectors is caused by different flux shape factors.

An example of the MIO application as trend recording is depicted in Fig. 6. It is measured to determine the neutron source in the primary cooling circuit[8]. Two BF_3 detectors are located near an outlet pipe. Two kinds of neutron sources are assumed - delayed neutrons coming from fuel surface contamination by uranium, and photoneutrons from the natural abundance deutrons in the coolant and concrete hit by high energy gammas from N-16. The difference in half-lives of delayed neutron precursors and N-16, causes different trends of neutron intensity after reactor trip, which can be predicted by calculations as in the figure. The measured trend is between two estimated trends, and it agrees well if it is assumed that the neutron source is composed of 30 % of photoneutrons and 70 % of delayed neutrons. This experiment confirmed to us that the delayed neutron measurement at the primary cooling circuit is a very sensitive and reliable method to detect the fuel failure.

Conclusions

A PC based data acquisition system has been effectively used for the reactor physics experiments as well as operator aid in Korean research reactors. Though changes of hardware and/or programs due to PC and I/O device development, requirement change in applications, etc., are not so rare, it is cost effective, convenient to use, and improves the quality of experiments and monitoring.

The current system is completely separated from the reactor operation computer because the requirements were not fully developed and available time was very limited at the design stage of HANARO operation computer. Since computer technology develops very fast, we are already considering replacement of the operation computer with a new one. It may need intensive study before the replacement, but those functions described in this paper should be included in the new system.

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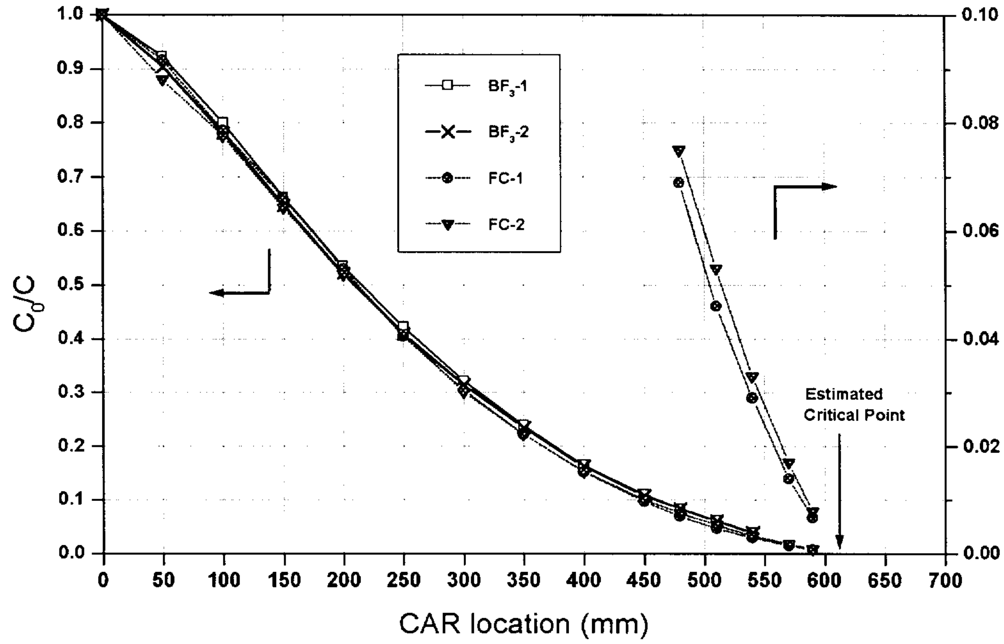

Fig. 1. Inverse multiplication curve depending on control absorber rods height for the initial criticality approach of HANARO.

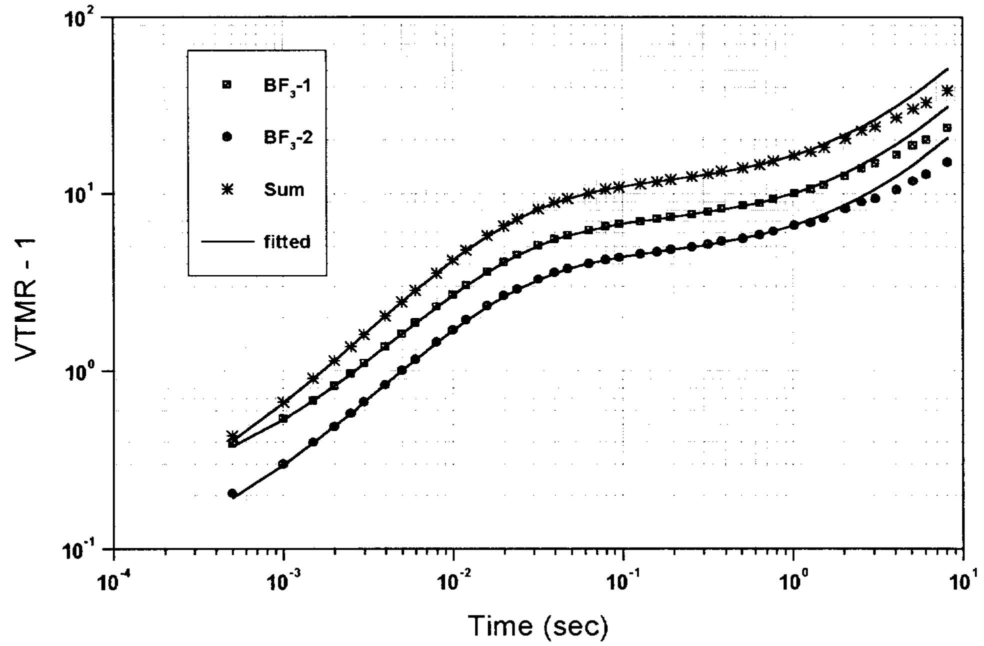

Fig. 2. An example of variance to mean ratio (VTMR) analysis

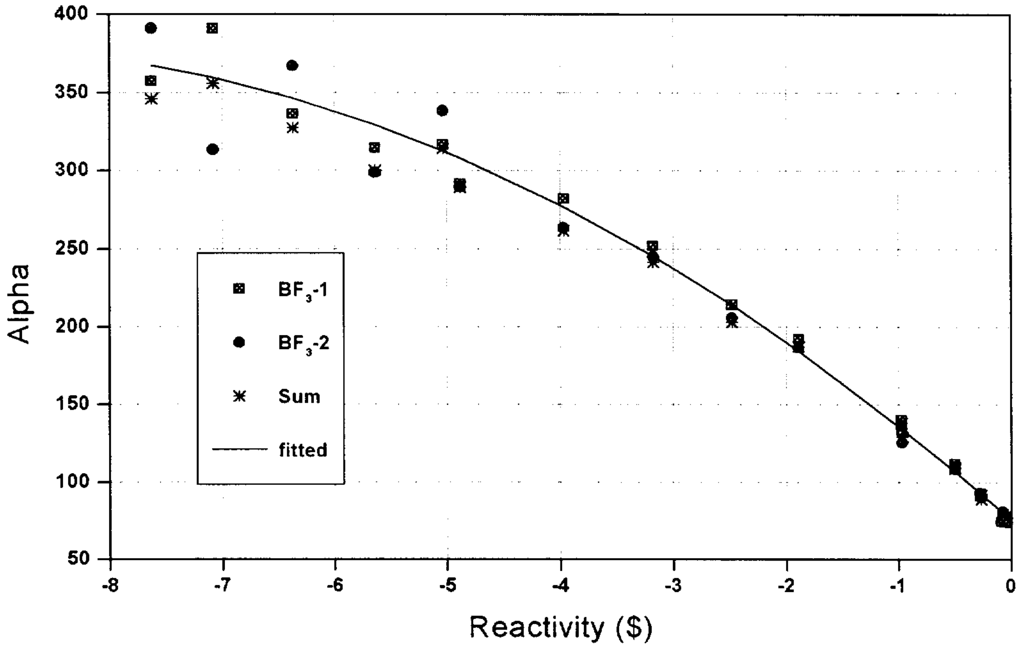

Fig. 3. The trend of prompt neutron decay constant (Rossi-α) depending on subcriticality

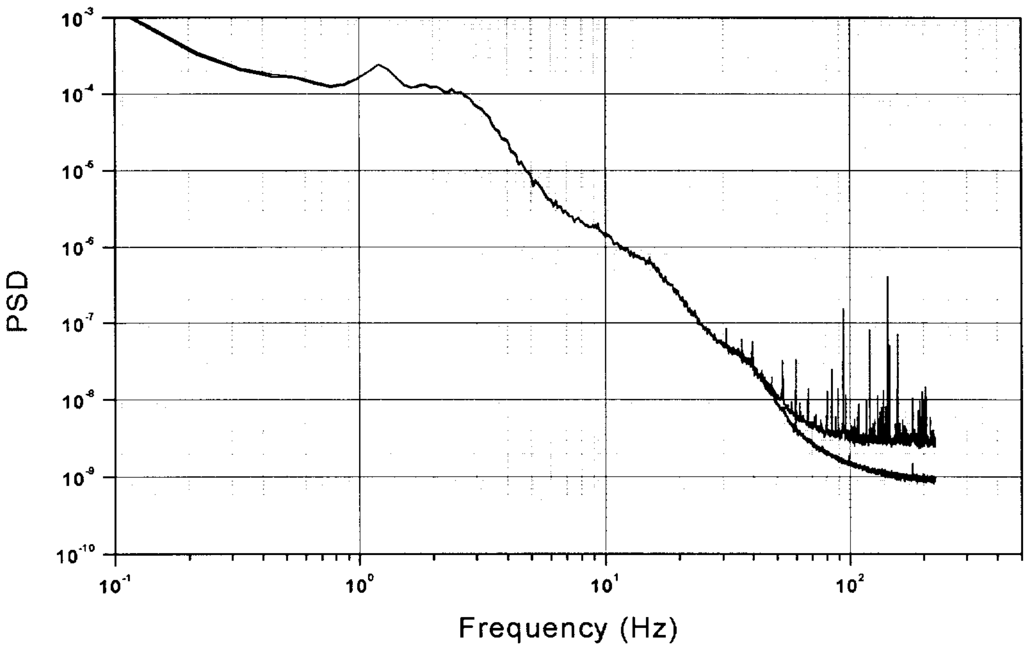

Fig. 4. An example of PSDs at 20 MW operation

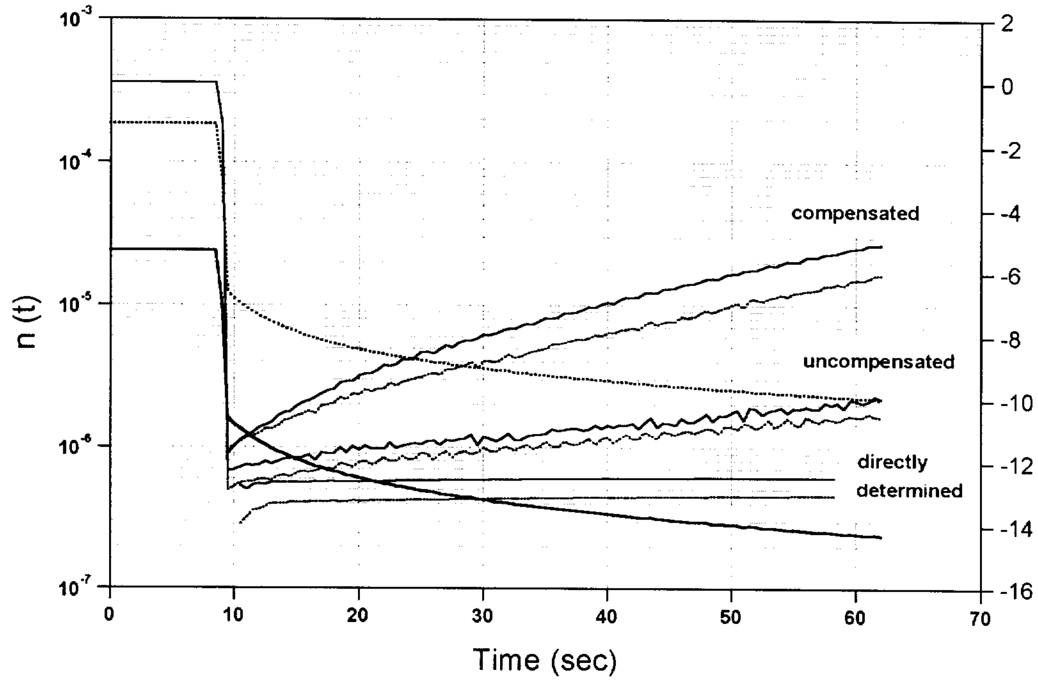

Fig. 5. An example of reactivity measurement by the reactivity meter when shut off rods drop

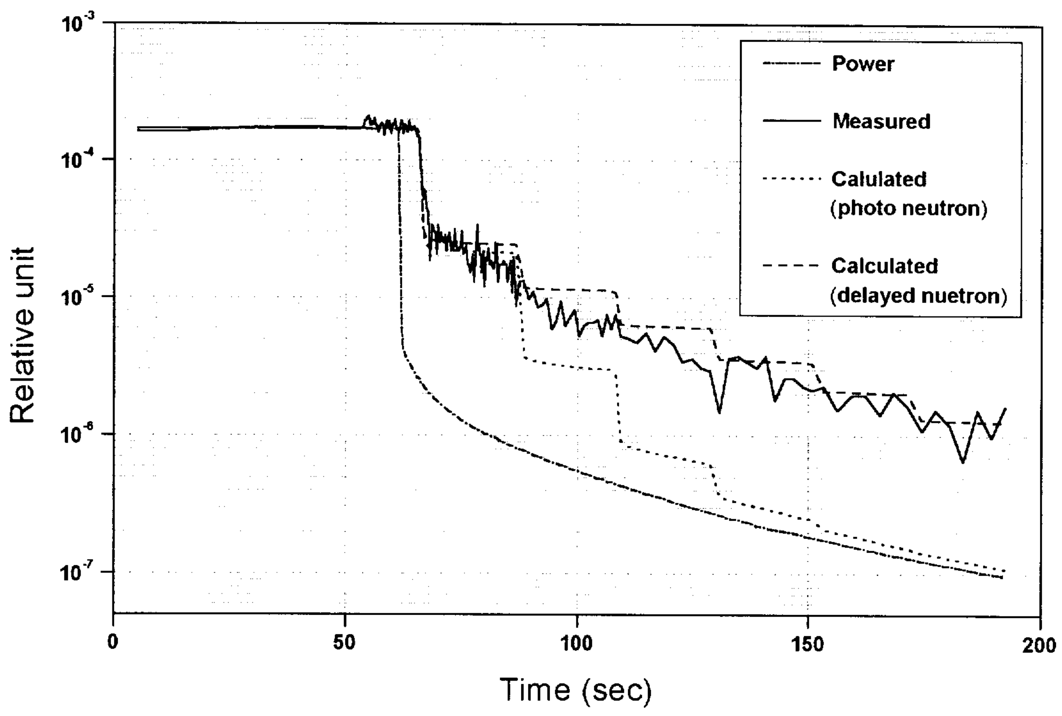

Fig. 6. Neutron intensity variation in the primary cooling circuit after reactor trip