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INVERSE KINETICS MEASUREMENTS USING THE SRM DETECTOR SIGNAL AT QUAD CITIES UNIT 2

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ABSTRACT

A preliminary investigation was made to determine whether the signal from a source range monitor would be useful as an input to an inverse kinetics calculation of reactivity. The results indicate general agreement between calculated values and those observed with instruments and encourage further investigation.

ACKNOWLEDGMENT

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1. INTRODUCTION

An experiment was conducted at the Commonwealth Edison Company, Quad Cities Unit 2 boiling water reactor (BWR) plant to determine the practicability of calculating reactivity on line, using a source range monitor (SRM) signal during startup. This study was part of a larger program to determine whether digital inverse kinetics methods are valid for inferring reactivity in large nuclear power plants and, in particular, to examine whether calculated reactivity is useful in designing automatic control systems. An accurate inverse kinetics method that operates on-line would also assist reactor operators during power operation and shutdown, as well as during startup. For example, control rod drive integrity could be verified by observation of reactivity changes during rod movement.

To make this special test, a transient SRM signal was generated by movement of a control rod under controlled conditions. With the reactor near critical during the normal startup procedure, a withdrawn rod was fully inserted into the core. A period of 4 to 5 min was allowed before and after the rod insertion for the reactor to reach steady state.

After the test was completed, the inserted rod was withdrawn, and the startup procedure was resumed. Recording of data was continued until the SRM detectors were retracted at 10^5 counts/sec.

Pulse signals from two SRM channels passed to a dual-channel count-rate meter (CRM), and the analog voltage signal from the CRM was recorded on a frequency modulated, two-channel tape recorder. The recorded data were returned to ORNL for analysis on the CDC-1700 process computer at the High Flux Isotope Reactor (HFIR).¹

1. J. B. Bullock and H. P. Danforth, Reactor On-Line Computer Control Development at the HFIR, Vol. 1: Objectives, System Design, Operating Experience, and Safety Considerations, ORNL-TM-3679 (October 1972).

The objective of the experiment was to compare the problems of monitoring reactivity in a BWR with those experienced at the HFIR.

2. APPARATUS AND PROCEDURE

2.1 Apparatus

The SRM system at the BWR included a fission chamber, 0.265 in. by 1.0 in. with a sensitivity of 1.50×10^{-3} count/nvt. a pulse height discriminator, a scaler, a count-rate circuit, and count-rate and period meters and recorders. The four SRM channels were identical, with the four chambers symmetrically placed about the center of the reactor core (Fig. 1).

The scaler output of shaped, voltage pulses at the fission chamber counting rate was connected to an external CRM (Fig. 2).

The CRM was an ORNL, dual, RC time-constant unit, Q-3136. The input was 50-nsec current pulses at a nominal rate of 10^3 to 5×10^6 pulses/sec. The anticipated count rate near critical was 10^4 counts/sec. The CRM had a pair of passive parallel RC networks for each range (with time constants from 1.3 to 1.9 msec), which integrated the current pulses, and generated an analog output of 1 to 10 V with bandwidths from 82 to 120 Hz.

Voltage pulses from the scaler in the SRM system were converted to current pulses at the CRM output by an EG&G, model T105/N, dual-channel discriminator. The input requirements of the discriminator were compatible with the voltage pulses supplied by the scaler, i.e., -10 V pulses, 2 μ sec width. The discriminator output fed to the CRM was 50-nsec current pulses.

The tape recorder was a Precision Instruments, model PS-207A, frequency-modulated, two-channel recorder. The nominal input and output voltage range was ± 1.4 V. The frequency response was from dc to

ORNL-DWG 73-5487R

- + CONTROL ROD
- ⊕ CONTROL ROD INSERTED DURING TEST
- LOCAL POWER RANGE MONITOR (LPRM)
- INTERMEDIATE POWER RANGE MONITOR (IRM)
- X SOURCE RANGE MONITOR (SRM)
- ⊗ 21, ⊗ 22 SRM DATA WERE RECORDED
- S SOURCE

Fig. 1. Location of control rods and monitors in Quad 2.

Fig. 2. Source range monitor and count-rate meter and recorder (only one channel shown).

~ 313 Hz at 1-7/8 in. /sec.

The system was assembled and calibrated at ORNL and then recalibrated at the reactor site. Pulses similar to those from the SRM scaler were obtained from a variable frequency pulse generator. The output voltage was measured at the CRM output, with the tape recorder connected and recording, by an oscilloscope and a digital voltmeter (DVM). Since the maximum range of the SRM was approximately 10^5 counts/sec, the system was calibrated only on the lower two of the four ranges, 5×10^3 and 5×10^4 (Fig. 3). The output signal from the recorder was measured by a DVM and oscilloscope during playback of the calibration data. The linearity of the system was excellent over the range of the recorder voltage of ± 1.4 V.

CRM channels 1 and 2 were connected to SRM channels 21 and 22, respectively, at the Unit 2 plant. Figure 1 shows that the detectors in

Fig. 3. CRM-recorder calibration.

these two channels are symmetrically placed about the center of the core. The inputs were capacitor coupled, and there were no loading effects on the scaler output.

2.2 Procedure

The startup of the Unit 2 plant followed a shutdown of ~ 6 weeks. The count rates before the control rods were withdrawn were 10 counts/sec on SRM channel 21 and 11 counts/sec on channel 22. These count rates were well below the lowest range of the CRM.

The rod withdrawal sequence is shown in Table 1. (Refer to Fig. 1 for rod locations.) From previous startup experience, criticality was predicted to occur at rod H-11. The preceding rod (F-09) in the sequence was selected to be inserted for the test. By observation of the period meters during rod withdrawal, indications of criticality were observed with rod H-07 at position 26. All preceding rods in the sequence had been fully withdrawn, and all other rods remained fully inserted. Rod H-07 was inserted to position 24 to assure a margin of subcriticality, and the reactor was allowed to stabilize for about 4 min. Rod F-09 was then fully inserted, using the rod-drive system. The rod insertion time was ~ 40 sec. For ~ 10 min following the rod insertion, data were recorded; during this period no rod motion occurred.

The CRM and tape recorder continued to record data from SRM channels 21 and 22 during withdrawal of rod F-09 to a fully withdrawn position and withdrawal of several succeeding rods in the sequence to rod L-02 in group 3 (Table 1). At this point, the reactor power was within the range of the intermediate range monitor (IRM) detectors and, according to normal operating procedure, the SRM detectors were retracted from the core. Then, the recording of SRM signals was stopped, and the CRM and recorder were recalibrated. Both sets of calibration data, pretest and posttest, showed little change.

Table I. Control rod withdrawal sequence for reactor startup^a

<u>Withdrawal Sequence (top to bottom)</u>			
Groups			
<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>
F-15 ^b	K-01	R-10	A-06
K-15	F-01	R-06	A-10
M-13	D-03	N-04	C-12
P-11	B-05	L-02	E-14
P-07	B-09	G-02	J-14
M-05	D-11	E-04	L-12
K-03	F-13	C-06	N-10
H-01	H-15	A-08	R-08
F-03	K-13	C-10	N-06
D-05	M-11	E-12	L-04
B-07	P-09	G-14	J-02
B-11	P-05	L-14	E-02
D-13	M-03	N-12	C-04
H-13	H-03	N-08	C-08
K-11	F-05	L-06	E-10
M-09	D-07	J-04	G-12
K-07	F-09	G-06	J-10
H-05	H-11	E-08	L-08
F-07	K-09	G-10	J-06
D-09	M-07	J-12	G-04
F-11	K-05	L-10	E-06
H-09	H-07	J-08	G-08

^aThe reactor is started up by withdrawing control rods, one at a time, from fully inserted to a fully withdrawn position until the reactor becomes critical. Of 35 groups of rods, the reactor became critical within withdrawal of the first two groups, and the reactor was released for this experiment by inserting rod F-09.

^bRod number in lattice position.

The elapsed time from the beginning of the rod withdrawal sequence to the rod F-09 insertion test, performed near critical, was ~ 1.3 hr. The total time from the start of rod withdrawal to withdrawal of the SRM detectors was about 2.15 hr, including the time spent during the test.

3. DATA REDUCTION AND ANALYSIS

The two recorded analog signals were analyzed at ORNL by two principal methods of analysis, both of which assume a point kinetics model. In the first, the analog signals were an input to the on-line dynamic reactivity routine of the CDC-1700 process control computer at the HFIR. This is a continuous, inverse kinetics calculation on a sampled analog input signal. Five delayed-neutron groups, used with the group constants for the HFIR (a 93% enriched, ^{235}U fueled, pressurized flux trap reactor with a nominal full power of 100 MW^2), were used for the analysis, because the BWR constants for the Unit 2 were not available. The BWR constants were received later, but since their values were so close to those for the HFIR, reanalysis of the data was not necessary.

The second method, called the "three point method," was developed in the Reactivity Surveillance Procedures Program at ORNL for the LMFBR program.³ Data in digital form, taken during a control rod drop, are used in a data-fitting routine, with the neutron source and the change in reactivity as parameters. Initial reactivity is calculated after the source term is determined.

2. R. D. Cheverton and T. M. Sims, HFIR Core Nuclear Design, ORNL-4621 (July 1971).

3. J. W. Allen, J. C. Robinson, and N. J. Ackermann, Jr., Statistical Errors in Subcritical Reactivity Inferred from Inverse Kinetics Rod-Drop Measurements Using the Three-Point Method, ORNL-TM-4101 (July 1973).

The main objective of this was to analyze the data taken during the special test (the insertion of rod F-09) and determine if a known rod movement under predetermined conditions could be detected by the analytical methods.

The response of the system to rod insertion was observed on the CRM for channel 1 (SRM channel 21) but not channel 2. As seen in Fig. 1, rod F-09 was closer to the SRM detector in channel 21. Two strip-chart recorders on the Unit 2 control panel recorded SRM channels 22 and 24. The detectors in channels 21 and 24 were approximately the same distance from rod F-09, and a response was recorded by the channel 24 recorder. The SRM strip-chart record for the rod F-09 test (Fig. 4) shows the count rates to the CRM and recorder preceding the rod insertion as 350 and 250 counts/sec on SRM channels 21 and 22, respectively. These rates were below the nominal range of the CRM. Oscilloscope monitoring of the CRM output to the recorder showed that there were overlapping

Fig. 4. Unit 2 strip-chart recorder trace during rod F-09 insertion.

random pulses present in this signal, indicating insufficient CRM integrating time constants at this count rate. Consequently, considerable noise was recorded along with the analog signals.

The signals were sampled on the CDC-1700 computer at a rate of 100 samples/sec (10 msec spacing). This rate corresponds to a maximum frequency of 4 Hz, which is sufficient to analyze the delayed-neutron response in this system.

The dynamic reactivity calculated by the HFIR method yielded a reactivity error band of $\sim \pm 1$ dollar. This large error was due to poor integration of the low count-rate signal by the CRM. To improve the integration, the recorded signals were fed to a voltage-to-frequency converter and the output count rate was totaled during successive 50-msec intervals. The count rate from the converter increased from 20 to 1.3×10^5 counts/sec as the input was increased from 0 to 1.35 V.

The conversion of recorded analog signals to digital form is diagrammed in Fig. 5. The analog signals received during insertion of

ORNL-DWG 73-5491

Fig. 5. Conversion of recorded analog signals to digital form.

rod F-09 and the subsequent increase in reactor power to 10^5 counts/sec were converted to digital format and stored on punched paper tape.

Recalculation of the dynamic reactivity by the first method yielded improved results. Converted data for the insertion of rod F-09 from SRM channel 21 (Fig. 6) shows that the neutron flux data were made smoother by averaging three adjacent points (150 msec sample spacing). The calculated reactivity (Fig. 6) was further smoothed by averaging 40 adjacent points, greatly reducing the frequency resolution of the calculation. The values preceding the rod insertion remained in an error band of about ± 10 cents, except for a number of peaks to 80 cents. Following insertion, the error band widened, and there were other very large peaks.

Results of better smoothing of the data are also shown in Fig. 6. The neutron flux data were made smoother by averaging 60 adjacent points (3 sec sample spacing). The reactivity was smoothed by averaging 40 adjacent points, as before. A result of this process was to reduce the frequency resolution of the analysis. As seen in the figure, the error band of the calculated reactivity values was ± 4 cents preceding rod insertion and ± 6 cents following insertion. The change in reactivity was determined to be about 17 cents.

The same digital data from insertion of rod F-09 were analyzed to determine the reactivity transient from the neutron flux data, using the three-point method and the same five-group, delayed-neutron constants as in the first analysis. The magnitude of the reactivity insertion and the neutron source term were the parameters in fitting the data. Data recorded at steady state before the rod drop were a measure of the mean count rate before the drop. Transient data, recorded during conditions of constant reactivity (i. e., after rod motion had ceased), were divided into two segments by specifying three time points in the transient data. The computer routine fitted these data to the neutron kinetics equations

Fig. 6. Dynamic reactivity calculation.

- a. Flux smoothed by averaging 3 adjacent points (150 msec dt)
- b. Flux smoothed by averaging 60 adjacent points (3 sec dt)

for each of the two segments and determined the magnitude of the neutron source term and the final reactivity of the system. The initial reactivity was inferred from the calculated source value.

The data values for this calibration were 100 msec apart (10 points/sec), including a period of 4 min to reach steady state before the rod was inserted. Data collected for about 2 min were used by the analysis program to calculate an initial average count rate prior to rod insertion. The rod insertion time was 40 sec. Then, transient data collected for 5 min were used in the calculation following the cessation of rod motion. The precise time at which insertion of rod F-09 was begun was specified in the program to be that time at which the average of 40 consecutive count rates per second was less than the initial average count rate. This was labeled Case 1. (This specification of initial rod motion was somewhat arbitrary.)

The results from Case 1 show the probable time of initial rod motion as earlier than the calculated time. Two additional runs were made (Cases 2 and 3) in which the initial rod motion was assumed to begin 5 and 10 sec before the insertion time described for Case 1. (Table 2). The analysis program included a statistical analysis of the data, in which it was assumed that the time of commencement of rod motion was known precisely and that the observed count rate data were proportional to the neutron density in the reactor core. Results from the three cases show considerable spread. Based on observation of the data, the time of initial rod motion in Case 1 was the most accurate. Data from this case are superimposed on the dynamic reactivity plot of Fig. 6. Results from the two methods agree reasonably well for this case.

Table 2. Reactivity for rod F-09 insertion calculated by the three-point method

Case No.	Insertion Time	Source	Reactivity (cents)		
			Initial	Final	Change
1	40 ^a	48,790 $\pm$ 3133	-85 $\pm$ 6	-124 $\pm$ 8	-39 $\pm$ 4
2	-5 sec	70,411 $\pm$ 5108	-122 $\pm$ 9	-178 $\pm$ 13	-56 $\pm$ 22
3	-10 sec	29,261 $\pm$ 1693	-51 $\pm$ 3	-74 $\pm$ 4	-23 $\pm$ 7

^aConsecutive points below initial mean count rate

4. CONCLUDING REMARKS AND RECOMMENDATIONS

The objective of the experiment was to determine whether SRM detector signals could be useful in an inverse kinetics calculation. Only qualitative, numerical results were obtained. Low count rates and a need to convert the data from digital to analog and then from analog to digital forms degraded the accuracy of the numerical results. Although point kinetics equations were used in the analysis and no spatial effects on the data were considered, the calculated worth of rod F-09 ($\sim$ 20 cents) is in line with rod worth estimates by Brammer et al.⁴ under startup conditions. Also, Table 2 indicates that the reactor was from 51 to 122 cents subcritical preceding the insertion of rod F-09. Following withdrawal of rod F-09, we observed by monitoring the reactor period meters during the withdrawal of succeeding rods in the sequence that a steady positive period indication was not reached until approximately position

4. H. A. Brammer et al., Nuclear Excursion Technology, APED-5528 (August 1967).

28 on rod N-04 (Table 1). This indicated that the reactor was probably subcritical preceding the rod F-09 insertion test.

Our observations indicate that there is at least a general agreement between the results of the calculations and the indications of the reactor instrumentation during the test. Even with the startup commencing near the minimum count rate of 10 counts/sec, counting statistics with the reactor critical were adequate for a practical start-up reactivity determination by digital techniques. The results encourage a more refined experiment in which the pulse data would be maintained in digital form. A scaler system of one to four channels would be needed for counting up to 5×10^5 counts/sec in intervals of about 100 msec and storing the data for further use. Whether an on-line computer in the BWR system could be used for this purpose should be investigated. Digital equipment especially tailored for such a measurement is available at ORNL for use on an experimental basis. Further feasibility studies could make use of either approach. This more refined experimental procedure may prove useful and should be pursued. In addition, analytic methods are available to determine the requirements for start-up channel counting rates for a required accuracy in the determination of reactivity. Such an analysis would prove useful in designing a start-up channel or in determining the limits of useful information contained in existing start-up channels.

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