Final Report to National Science Foundation

Research Initiation Grant: GK-1572 Rapid Rod Calibration in a Nuclear Reactor

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SUMMARY:

A rapid reactivity measurement and rod calibration method has been implemented. The technique, solving the inverse reactor kinetics equations, is being applied to available time-sharing computer systems. The input information is digital data from neutron detectors in a nuclear reactor. These data are collected while the device to be calibrated is moved between the measurement positions. Several detectors operating simultaneously permit the space-dependent information contained in the reactor transfer function to be evaluated as a correction factor. Time-sharing computers and telephone equipment enable the power of a scientific computer to be obtained economically and provide rapid response. The use of standard nuclear data-collection instruments as well as a more flexible data-acquisition system incorporating a PDP-8 laboratory computer has been under investigation. Efforts are continuing to understand the effects of reactor configuration and input parameters on results, and to identify a simple, economical system which will permit widespread application of this rapid method for power reactor measurements of reactivity.

DISCUSSION OF THE RESEARCH:

The inverse kinetics method for calibrating control rods dates back several years,[1] but its use has not been widespread. Traditional reactivity measurement methods are tedious and, as a result, the control and safety rods of reactors are usually calibrated at infrequent intervals. Some use of the inverse kinetics technique has been made through analog computer equipment referred to as a "reactivity meter". This equipment lacks the flexibility and adaptability offered by a digital inverse kinetics algorithm, especially if one is interested in incorporating space-dependent information in the solution.

In our research we have prepared four parallel neutron detection channels as shown in Figure 7 of the attached paper. Two of these detectors are fission chambers and two are neutron scintillators mounted on photomultiplier tubes. These channels have been operated at high count rates and the inverse kinetics model applied in a limited fashion in the configuration of Figure 6. We have just completed the construction of the interface indicated in Figure 7, which provides experimental timing and control and effects the transfer of information from the 100 MHz scalers into the PDP-8 computer. The program which manages the data in the PDP-8, correcting for dead-time and formatting for output, has been completed, as have the programs which accomplish harmonic analysis of the neutron data on a large-scale computer, in this case, the Univac-1108.

The reactivity control device which we are using for this research is a pile-oscillator with cadmium absorber. The oscillator is mounted in a horizontal beam tube of the Georgia Tech Research Reactor. It has a worth of 0.4%, which is typical of many control rods, and provides the ability to insert and remove reactivity at different rates with a variable speed motor. Additionally, the reactor source transfer function can be measured with this device and its information, which accounts for frequency and detector location, incorporated into the inverse kinetics model. Several points on the transfer function curve have been measured for the present reactor core configuration. In theory, if one has a complete space-dependent transfer function for all points of a reactor, then a flux vs. time measurement at one point should permit prediction of measurements at all other points through a frequency analysis of the propagating disturbance. R. J. Johnson[2] has proved that one can calculate such transfer functions using standard reactor statics codes. We are measuring the transfer function rather than calculating it because it is uniquely practical to do so for our experiment. We are preparing to experimentally determine whether that which one should be able to do in theory (i.e., predict space-dependent response) he can do in fact. If this is true the benefit will be that transfer function information will replace neutron detection channels in accounting for the space-dependence of detector response in reactivity measurements.

An additional goal is to define the necessary and sufficient instrumentation to couple the neutron detection channel with a powerful time-shared computer system. The implication of an economical configuration (perhaps even a portable one which could be shared among several installations) would be a field capability to calibrate control rods rapidly and at frequent intervals, limiting unexpected worth changes which might adversely affect reactor safety.

In addition, the sensitivity of this method to speed of reactivity change and different neutron absorbers is to be studied.

REFERENCES:

1. C.E. Cohn and J.J. Kaganove, Trans. Am. Nucl. Soc. 5, 388, (1962).

2. R.J. Johnson and R.M. Macdonald, Proceedings of the Symposium on Neutron Noise, Waves, and Pulse Propagation, University of Florida, Gainesville, Florida (1966).

GRANT ACTIVITIES:

a. Papers

A paper entitled "Time Sharing Computers in Nuclear Engineering Education", a portion of which dealt with research sponsored under this grant, was delivered at the 14th Annual Meeting of the American Nuclear Society in Toronto, Canada, June 1968. The summary appears in Trans. Am. Nucl. Soc. 11, 46 (1968). Two copies of this paper are attached to this report.

b. Personnel

*W. W. Graham, III - Assistant Professor of Nuclear Engineering

*R. J. Lord, Graduate Research Assistant

R. E. Patrick, Ph. D. Candidate

*J. C. Alderman, Data Acquisition System Engineer

*Supported by grant.

c. Related Activities of Interest to the Foundation.

The grant influenced activities in nuclear engineering education as indicated in the paper mentioned above, copies of which are attached. It has also influenced the scope and goals of Mr. R. E. Patrick's Ph. D. thesis which is in the area of this work. Mr. Patrick participated in this research although he was not directly supported by it since he holds a traineeship. Mr. Lord, who was supported by this grant, is applying experience which he has gained in this research to an experimental Ph. D. thesis involving pulsed neutron measurements of slowing-down times in reactor coolants.

In addition, this research initiation grant has led to the formulation of a rather significant related problem in reactor kinetics which will have the following objectives:

a) Development of a comprehensive two-dimensional, two-energy group calculational program for the analysis of r-z models of Georgia Tech Research Reactor transients and their implementation on a UNIVAC-1108 computer.

b) The design and execution of experiments to test this calculational model with actual data obtained from a specially-instrumented GTRR core operating in conjunction with the powerful data acquisition capability and much of the same equipment developed in the course of this grant.

c) Evaluation of the accuracy and efficiency of the numerical methods employed in order to indicate the regions of their applicability and relative desirability.

The design of special apparatus for this research and a first approximation to the calculational model have been completed.

TIME-SHARING COMPUTERS IN
NUCLEAR ENGINEERING EDUCATION

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Presented at the 14th Annual Meeting of the American Nuclear Society
in Toronto, Canada
June 12, 1968

Time-Sharing Computers in Nuclear

Engineering Education*

by

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In the computer field time-sharing has assumed increasing importance over the past two years. Some experts predict that it will represent 50% of the industry by 1970. What it is and how and why it can be significant in nuclear engineering education is the subject of this paper.

Time-sharing in its broadest definition exists whenever several users not physically at the location of the main hardware have the ability to access the central processing unit simultaneously. More than any other single phase of computing, time-sharing has emphasized the critical importance of software in the computing process. Some of the most successful time-sharers have been computers which were far from advanced in their hardware, but which possessed innovative system software; other exotic time-sharing hardware systems are still on the starting blocks because of software lags. The following table illustrates the point that time-sharing machines are the old familiars:

Table I. Central Processors Currently Used in Time-Sharing [1]

GE-225	PDP-6	IBM 1620
GE-235	PDP-8	IBM 360/40,50,65
GE-420	PDP-9	IBM 7044
GE-635	PDP-10	IBM 1460
B-300	UNIVAC-491	PHILCO-212
B-5500	UNIVAC-1107	
	UNIVAC-1108	SDS-940
DATA-620		
	IBM 1440	
H-2200	IBM 1441	

The impact of these systems has been significant, especially on small computationally oriented scientific and engineering firms. Even grander things

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are promised for the new generation machines when their time-sharing software is implemented. While current systems permit as many as 200 simultaneous users, educational configurations on the drawing boards envision 4000 simultaneous users of a single system[2].

Time-sharing has implications considerably more far-reaching than the most obvious one, that of computer use in a conventional way without having to walk to the computer center. A new spectrum of problems which can be solved economically with the computer is defined. Since there is a tremendous acceleration of the "debugging" process, the time between first program definition and the receipt of correct answers is short enough to make one-time-solution problems feasible. More exciting and perhaps even more consequential is the new dimension in computing which is discovered by the time-sharing user, that of a partnership between man and machine. One gains a fondness for a machine which is almost always available, genie-like, to do his bidding, calculationally at least. For certain experimental procedures there is also the possibility of using the time-shared computer in a manner approaching real-time operation, permitting display of computed results and facilitating subsequent decisions, all without the capital expense of an installed system.

For a comprehensive survey of time-sharing services and their costs, Reference 1 is recommended. It is sufficient here to comment that one can obtain a minimum block time of eight hours access time for as little as $108/month plus terminal and telephone costs, which add about $90/month. Therefore, time-sharing has achieved the reputation of being the only kind of computer power cheaper to try than to make feasibility studies on. Special educational use contracts are also offered by some suppliers. It seems inevitable that the more sophisticated systems will make time-sharing ridiculously economical. The 4000-user educational system predicted for the early 1970's by Dr. Donald L. Bitzer of the University of Illinois computer-assisted instruction project will provide remote computer access for about 25¢/hour, including special purpose terminals with random-access slide projectors and memory screens under computer control and the associated communications equipment.[2] Such cheap,mammoth systems must inevitably affect our educational methods in a drastic way.

Now let's turn to the applications which have been made of this type of computing in the School of Nuclear Engineering at Georgia Tech. They serve only as indicators of the possibilities in nuclear engineering education.

Use in the classroom itself has been limited to the following:

1. A GE-255 demonstration of the use of such an interactive system in trial-and-error solution of the transcendental equation which results from the six-factor criticality equation with unknown buckling.

2. Demonstration of the remote access to a B-5500 disk-stored one-dimensional, two-energy-group ALGOL diffusion code for subsequent student use in homework problems.

3. Construction of a Bessel function generator with the BASIC language and demonstration of its convergence properties using the GE-255 as shown in Figure 1.

Time-sharing has been most effectively used as a labor-saving device by nuclear engineering graduate students in the course of solving assigned problems and in reducing laboratory data as typified by the following:

1. In a Nuclear Engineering Fundamentals class for students taking a Radiological Safety option, the assignment to solve the xenon poisoning problem was worked remotely on the Burroughs B-5500 using the INTERP language as shown in Figure 2.

2. In a Reactor Safety class, reactor transients involving step and ramp insertions of reactivity were investigated using Call-a-Computer BASIC. The conversational nature of time-sharing is illustrated in Figure 3 which reproduces a step insertion solution. User responses have been underlined for clarity.

3. In a Nuclear Engineering Laboratory course, time and space-dependent data from a thermal neutron detector monitoring the decay of a neutron burst in a moderator volume were harmonically analyzed during the course of the experiment through the use of a FORTRAN program, shown with sample results in Figure 4.

4. An interesting new small computer entry in the time-shared field is the PDP-8 with multi-user FOCAL. We use our PDP-8 from both the Nuclear Research Center, where it is located, and from the Nuclear Engineering Building, a block away, by telephone. Digital Equipment Corporation's PDP-8/I will feature a FOCAL version permitting eight simultaneous users. A sample of a FOCAL program to carry out the integrations of areas under a plot of foil activity times the square of distance from neutron source (Ar^2) and an Ar^4 curve, as required in a migration area experiment, is shown in Figure 5.

Time-sharing has played a particularly important part in one phase of our research. We have been investigating reactivity measurement and calibration methods with considerable emphasis on the inverse kinetics method. This technique, which goes back several years,[3] solves the reactor kinetics equations for reactivity as a function of time, given the kinetics parameters and a measure of neutron density as a function of time. Such data are usually obtained from a detector during the driving-in of an absorbing control rod from its full-out to full-in position.

Analog equipment in the form of a "reactivity meter" is most often used when this method is employed with commercial reactors. The flexibility and adaptability of a digital inverse kinetics algorithm recommends it, especially if one is interested in incorporating detector location information in order to allow for space dependence of response in large reactors. Time-sharing and telephone equipment permit the capability of a digital method to be called on economically and provide a rapid turn-around which can affect subsequent procedures.

The use of standard nuclear data-collection instruments (multichannel analyzers) as elements in a time-shared control rod calibration scheme has been reported earlier.[4] The advantage in such a system, illustrated schematically in Figure 6, is recognized if you have as many analyzers as detectors. You can even use the analyzer cathode ray tube as a display device for computer results. The disadvanges appear as one seeks to increase the number of detectors operated simultaneously and improve graphic display capability, and as one becomes limited by the scaling capability of the analyzers (2MHz in this modified TMC equipment).

As a result of these limitations, we are assembling a very flexible system shown in Figure 7. Here the experiment is under computer control, includes high-speed scalers, and permits faster data transmission and improved display and data recording capability. This configuration is being completed just this month, so no results are available. However, the purpose of the multiple detectors is to investigate space-dependence, power history, and rod-speed effects and test an expanded inverse kinetics model. We hope this model will be able to account for differences which have been observed in the response of detectors at different locations. Of course, the engineering goal is not to build the fanciest system possible, but the simplest. Through this very versatile configuration we intend to identify the necessary and sufficient instrumentation to use with time-shared computers for reactivity measurements.

During the period of this investigation, the time-sharing service offered through General Electric equipment by several firms at many locations has had the combined advantages of versatility, reliability, availability, capacity, and power that have made it attractive. Literally overnight advances in the state-of-the-art can change the picture on the best system for a given application. We currently find ourselves in a time-sharing buyer's market with 80 or more locations providing service. Since time-sharing permits easy programming and is a convenient, economical means of bringing the computer into the classroom, laboratory and even the home, it is unquestionably here to stay.

References

1. Modern Data Systems, Vol. 1, No. 1, pp. 40-50, February 1968.

2. Personal Communication, Dr. Donald L. Bitzer, University of Illinois, May 1968.

3. C.E. Cohn and J.J. Kaganove, Trans. Am. Nucl. Soc. 5, 388, (1962).

4. W.W. Graham et al., Trans. Am. Nucl. Soc. 10, 17, (1967)

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LIST


WW1       10:43    CAC FRI01/20/67

 5 REM CONVERGENCE ILLUSTRATION-BESSEL FUNCTION OF THE FIRST KIND
10 PRINT"WHAT IS ORDER AND ARGUMENT";
15 INPUT N,A
20 LET J=0
25 LET F=1
30 LET F1=1
35 FOR K=0TO100
37 IF K=0THEN50
40 LET F = F*K
45 LET F1 = F1*(K+N)
50 LET J=J+(((-1)↑K)/(F*F1))*(A/2)↑(N+2*K)
55 PRINT "J=  "J
60 NEXT K
99 END

RUN


WW1       10:44    CAC FRI01/20/67

WHAT IS ORDER AND ARGUMENT?0,1.1
J=    1
J=    .6975
J=    .72037
J=    .719608
J=    .719622
J=    .719622
J=    .719622
J=    .719622

STOP
READY
```

Figure 1. BASIC Bessel Function Solution Demonstrating Convergence

```
LIST←

1.1 SET GI=6.1@-2; LI=1.038@-1
1.2 SET FLUX=1.00@+14; LX=7.54@-2
1.3 SET SIGX=3.00@-18; EOD=1.75@+17
1.4 SET XEN=1.63@+16; TIME=0.0
6.1 SET XOT=(LI/(LX-LI))\EOD\(EXP(-LI\TIME)-EXP(-LX\TIME))
6.2 SET PDQ=XEN\(EXP(-LX\TIME))
6.3 SET ZOT=XOT+PDQ
6.6 SET POIS=ZOT\SIGX
6.8 TYPE TIME; POIS FORM 1
6.9 SET TIME=TIME + 2.0
FORM 1 LINE "TIME "III "HRS    XE POISON "F.FFF

DO PART 1←

DO PART 6 UNTIL TIME EQL 14.0←



TIME   0 HRS    XE POISON 0.049

TIME   2 HRS    XE POISON 0.133

TIME   4 HRS    XE POISON 0.188

TIME   6 HRS    XE POISON 0.222

TIME   8 HRS    XE POISON 0.240

TIME  10 HRS    XE POISON 0.246

TIME  12 HRS    XE POISON 0.244

TIME  14 HRS    XE POISON 0.236
```

Figure 2. Xenon Poison Calculation Using B-5500 INTERP

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GHW      21:51   THU.   10-26-67

WHAT IS THE INITIAL POWER IN KILOWATTS? .001
WHAT IS THE VALUE OF THE STEP INSERTION (FRACTION)? .05
WHAT IS THE INITIAL K EFFECTIVE? 1.00
WHAT IS THE EFFECTIVE LIFETIME (SEC)? 2E-4
WHAT IS BETA? .0064
FOR WHAT TIME DO YOU WANT THE TOTAL ENERGY RELEASE? .1
DO YOU WISH TO SPECIFY COMPUTATION TIMES BY WIDTH AND NUMBER
OR DO YOU WISH TO INPUT SPECIFIC TIMES.  IF BY WIDTH AND
NUMBER TYPE 1, IF SPECIFIC TIMES TYPE 0?  1
OVER WHAT TIME INTERVAL DO YOU WISH POINTS? THAT IS, WHAT
IS T(INITIAL) AND T(FINAL)? 0.00, 0.15
HOW MANY POINTS ARE DESIRED? 16

                    S O L U T I O N

PERIOD WITH NO FEEDBACK=  4.62107 E-3   SEC
TOTAL ENERGY RELEASE WITH NO FEEDBACK =  3.2105 KWHR
INITIAL INJECTED REACTIVITY = 216.4   SEC -1
REACTIVITY COEFFICIENT = 9.36164 E-3   (SEC 2 KW)-1
A = 1.00044 E 10   DIMENSIONLESS
R = 216.4    SEC -1
TIME OF MAXIMUM POWER =  .106406  SEC
TIME OF MAXIMUM SLOPE =  .10032  SEC
```

TIME	INTEG POWER	POWER	POWER SLOPE
0	0	.001	.2164
.01	9.89152 E-9	8.70589 E-3	1.88395
.02	9.60060 E-8	7.57925 E-2	16.4015
.03	8.45710 E-7	.695842	142.79
.04	7.37254 E-6	5.7445	1243.11
.05	6.41942 E-5	50.0106	10822.2
.06	5.58856 E-4	435.353	94202.2
.07	4.86372 E-3	3787.6	819015.
.08	4.22198 E-2	32782.8	7.04755 E 6
.09	.358479	271474.	5.54672 E 7
.1	2.5684	1.60071 E 6	207836136
.11	8.79915	2.15802 E 6	-1.72962 E 8
.12	12.1982	476381.	-9.27532 E 7
.13	12.7646	59918.8	-1.28102 E 7
.14	12.8331	6956.57	-1.50331 E 6
.15	12.841	800.049	-173103.

Figure 3. Conversational Solution for
Reactivity Transient Problem

```
5HARMONIC ANALYSIS FOR PULSED NEUTRON DATA
10 PRINT,"GIVE BACKGROUND FOR EACH POSITION IN ORDER"
15 INPUT, A,B,C,D,E
20 PRINT,
35 35 PRINT,"WHAT ARE TIME AND 5 COUNTS(1 EACH Z POSITION)"
40 INPUT, T,F1,F2,F3,F4,F5
45 PRINT,
50 F1=F1-A/4; F2=F2-B/4; F3=F3-C/4; F4=F4-D/4; F5=F5-E/4
100 B1=.3333333*(.5*F1+.866*F2+F3+.866*F4+.5*F5)
105 B2=.3333333*(.866*F1+.866*F2+0-.866*F4-.866*F5)
110 B3=.3333333*(F1+0-1*F3+0+1*F5)
115 B4=.3333333*(.866*F1-.866*F2+0+.866*F4-.866*F5)
120 B5=.3333333*(.5*F1-.866*F2+F3-.866*F4+.5*F5)
195 PRINT,"TIME    ",T,"  MICROSECONDS"
196 PRINT,
200 PRINT,"B1 = ",B1
205 PRINT,"B2 = ",B2
210 PRINT,"B3 = ",B3
215 PRINT,"B4 = ",B4
220 PRINT,"B5 = ",B5
225 PRINT,
300 GO TO 35


GIVE BACKGROUND FOR EACH POSITION IN ORDER
?23,14,9,4,6

WHAT ARE TIME AND 5 COUNTS(1 EACH Z POSITION)
?190,49951,61216,49635,33608,16694

TIME          190.00    MICROSECONDS

B1 =     55021.765
B2 =     17567.746
B3 =      5668.3328
B4 =      1630.1727
B5 =       279.3127
```

Figure 4. FORTRAN Solution for
Pulsed Neutron Harmonic Analysis

```
C-FOCAL., 1968

01.03 T "N"; A N
01.04 F I=1,1,N-1; D 2.0

02.03 T % 2 I,!
02.04 T "A";A A(I);T "R";A R(I)

03.03 S S(1)=(A(2)-A(1))/(R(2)-R(1))
03.04 S S(N)=(A(N)-A(N-1))/(R(N)-R(N-1))
03.05 F I=2,1,N-2; D 4.0

04.03 S S(I)=(A(I+1)-A(I-1))/(R(I+1)-R(I-1))

05.03 F I=1,1,N-1; D 6.03

06.01 S R(17)=R(16)+2
06.03 S A(I)=A(I)-6.8125*S(I)/(R(I)*24)
06.04 F I=1,1,N-1; D 7.0

07.03 S S(I)=A(I)*R(I)↑2

07.03 S S(I)=A(I)*R(I)↑2
07.04 S A(I)=A(I)*R(I)↑4

08.02 F I=1,1,N; D 8.21
08.03 F I=1,1,N; D 8.22
08.21 S X=X+(S(I-1)+S(I))*(R(I)-R(I-1))/2
08.22 S Y=Y+(A(I-1)+A(I))*(R(I)-R(I-1))/2
09.03 T %
09.04 T "X",X,!
09.05 T "Y",Y,!
*
```

Figure 5. PDP-8 FOCAL Program for Numerical Integration of Migration Area Data

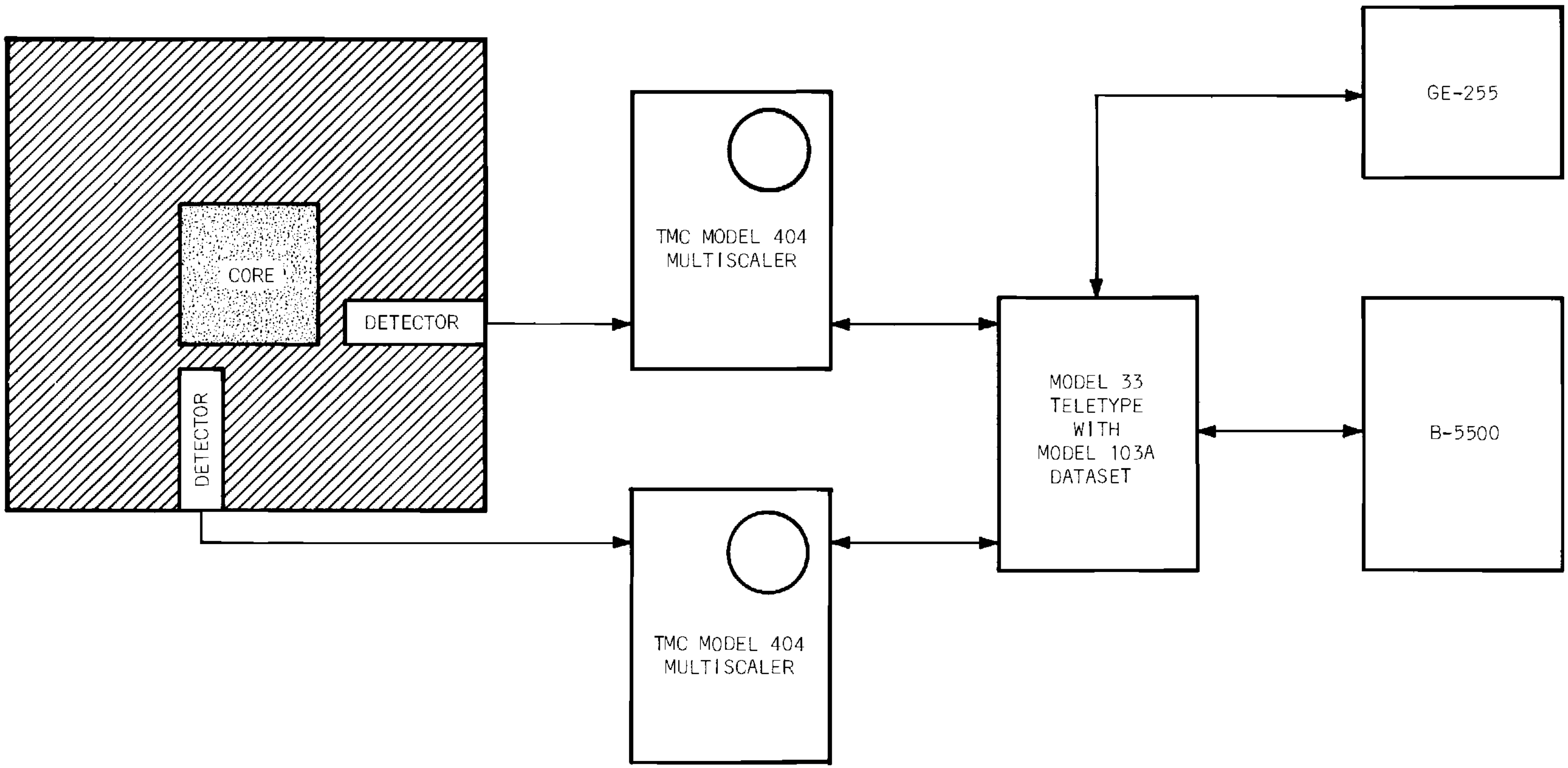

Figure 6. Reactivity Calibration Equipment Schematic (Multiscaler Method)

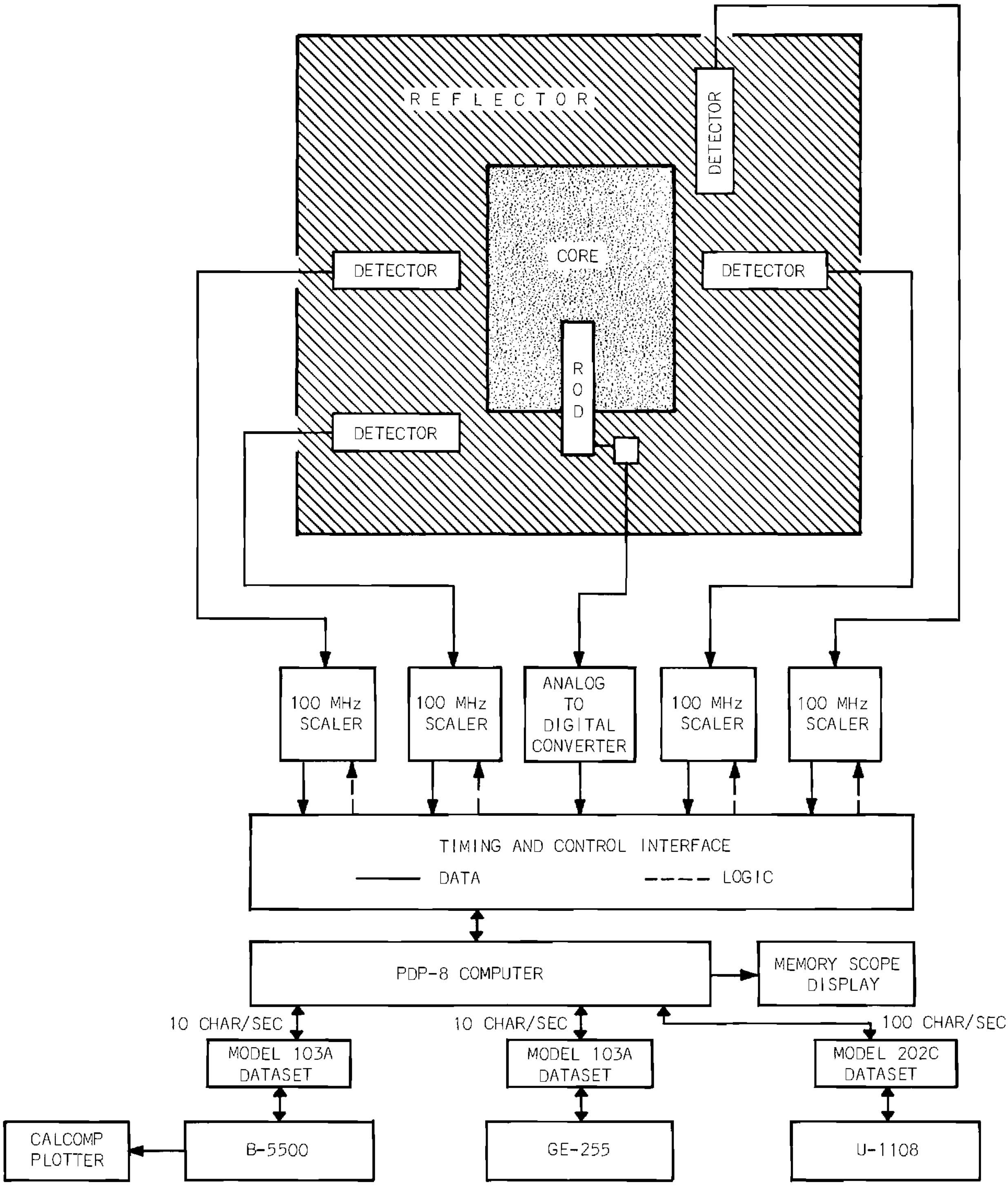

Figure 7. Reactivity Calibration Equipment Schematic (Lab Computer Method)