NSA 14-10384

NAA-SR-MEMO-5337

PROCEDURES FOR LOW-POWER PHYSICS EXPERIMENTS IN THE SRE

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PROCEDURES FOR LOW-POWER PHYSICS EXPERIMENTS IN THE SRE

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P.O. BOX 309 CANOGA PARK, CALIFORNIA

ISSUED: AUGUST 1, 1960

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INTRODUCTION

The Sodium Reactor Experiment (SRE), a sodium-cooled graphite-moderated reactor, has been described in detail elsewhere.*,†,§ The original fuel assemblies, which contained seven rods of slightly enriched uranium, have been discharged, and preparations for the second loading are in progress. The new fuel clusters will be five rods of a thorium-uranium alloy containing 7.1 wt-% U^{235}.§,**

This report is a compilation of the procedures for the low-power physics experiments to be performed with the second fuel loading. During the experiments the reactor power level will remain below 120 kw. The experiments will measure various parameters, such as the critical mass, shim rod worths, statistical weights, the isothermal temperature coefficient, and the reactor transfer function. The measurements will provide data which are needed for reactor operation, studies of reactor behavior, and development of the sodium graphite reactor concept.

The sequence in which the experiments will be performed is given below. The letters indicate the chronological order, and the Roman numerals indicate the order of presentation in this report.

a) Critical loading experiment (II) including the setup of instrumentation (I)

b) Setup and test of the period and temperature measuring equipment (III)

c) Shim and safety rod calibrations by period measurements (IV)

d) Shim rod calibrations with the reactor oscillator (V)

e) Measurement of the radial statistical weight (VI)

f) Measurement of the axial flux traverse (VII)

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*C. Starr and R. W. Dickinson, Sodium Graphite Reactors, (Reading, Mass.: Addison-Wesley Publishing Company, Inc., 1958).

†"Hazards Summary for Thorium-Uranium Fuel in the SRE," NAA-SR-3175 (Revised).

§G. E. Deegan et al., "Design Modifications to the SRE during FY 1960," NAA-SR-5348.

**D. H. Johnson, "Addendum to Hazards Summary for Thorium-Uranium Fuel in the Sodium Reactor Experiment," NAA-SR-3175 (Revised) Supplement.

g) Measurement of the reactor transfer function with the reactor oscillator (V)

h) Measurement of the amplitude of the reactor transfer function in the high-frequency region by noise analysis techniques (VIII)

j) Measurement of the axial statistical weight (IX)

k) Measurement of the isothermal temperature coefficient of reactivity (X)

The experiments will be performed on the standard SRE three-shift operation, and will require approximately 43 days.

The procedures in this report are not intended as technical evaluations of the experiments. They are the detailed, step-by-step procedures to be followed during the experiments, and are written for the engineers and technicians who will perform the experiments.* Standard operating procedures will be followed unless otherwise noted.† Later reports will discuss the experiments and the results from the technical viewpoint.

In addition to the procedures, this report includes a Glossary, which defines the special terms used in the procedures, and two general appendices. Appendix I describes the safety channels for the SRE and lists all changes made in them during the experiments. Appendix II contains a core map of the reactor showing the operational loading, and lists chronologically all changes made in the loading as required for the experimental program.

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*"Organization of the Sodium Reactor Experiment Group," NAA-SR-Memo-5360.
†R. E. Durand et al., "SRE Standard Operating Procedures," NAA-SR-Memo-5326.

GLOSSARY

The terms or symbols defined below are those which appear in the procedures without definitions, but which are not in common usage elsewhere, or which are used here with a different meaning.

"A," "B," "T," "C," "P" refer to five different flux levels of the reactor. They are discussed in Experiment III. "T" is the flux level at which the temperature of the fuel has risen 1/2°F, which will be about 0.02% of full power. "B" is one decade below "T," and "A" is three decades below "T." "C" is the flux level at which the fuel channel exit temperature starts to rise, which will be about 0.3% of full power. "P" is 1/3 decade below "C," or about 0.1% of full power.

Dummy Assemblies are graphite logs canned in either zirconium or stainless steel. They are used in corner channels, and in all center channels not occupied by fuel assemblies, in order to reduce the amount of sodium in the unused channels.

Low Power refers to power levels less than about 120 kw. For example, at a flow rate of 1000 gpm, this corresponds to a change in temperature across the core of 3°F.

(O), (E), (S), (H) appear at the beginning of the steps in the procedures to indicate the personnel responsible for performing the step. (O) refers to the Operations Unit, (E) to the Experimental Unit, (S) to the Systems Unit, and (H) to Health Physics.

Operational Loading is the reactor fuel loading which will be used for high-power operation. It is defined as the number of fuel clusters at which the excess reactivity of the core is equal to one-half the combined worth of the four shim rods, and will be about 33 clusters.

Ganged Shim Rods describes two or more shim rods at a common level in the reactor. Motion of the "gang" is accomplished by moving the shim rods individually to a new common level.

Special Graphite Thimbles are zirconium thimbles containing hollow graphite logs. The neutron-sensitive thermopile is placed in one of these thimbles to reduce the neutron streaming around the thermopile.

Veeder Unit (V.U.) is the unit of distance used to measure shim rod motion. It is defined as a change of one unit in the last digit of the Veeder counter on a shim rod drive, and corresponds to 1/160 inch of linear shim rod motion.

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I

SPECIAL INSTRUMENTATION FOR THE CRITICAL EXPERIMENT

By

R. A. LEWIS

CONTENTS

FIGURES

OBJECTIVE

The objective of this experiment is to set up and test the special instrumentation for the Critical Loading Experiment.

PURPOSE

This experiment is designed to assure accurate and reliable operation of the special instrumentation, which is essential to the success of the Critical Loading Experiment.

METHOD

Neutron detection during the approach to criticality will be provided by three special high-temperature fission chambers located in the reflector region on the reactor midplane. These chambers were built by Westinghouse as part of their new line of miniature high-temperature (600°F) "flux mapping" fission chambers. Extensive calibration and testing of these chambers has already been performed in connection with the use of these chambers for detecting sodium in the moderator cans. One of the chambers, located in a thimble in the SRE core, has demonstrated satisfactory operation over a 30-hour period at 290°F.

The physical setup of the instrumentation is shown schematically in Figure I-1. Operations will provide a rate meter and period meter, which will be connected in parallel with one of the scaler channels. Safety interlocks and scram circuits will also be provided by Operations through this channel.

Testing of the equipment will include an inspection of the shape of the pulses leaving the amplifier, a recheck of the pulse height calibrations, and a check for normal statistics in the counting data.

PROCEDURE

Section I should begin as early as possible. Sections II and III are to be performed just before the Critical Test. All steps in this procedure are to be performed by Experimental Unit personnel (E).

I. PREOPERATIONAL TEST AND CALIBRATION

A. Laboratory Setup of Pulse Counting Channels

1. Check of Operating Voltage

1. Set up the three counting channels, from the preamplifiers to the printers, as shown in Figure I-1, in the Sanborn Room. Connect the 50-ft B+, filament, and signal cables between the preamplifiers and the amplifiers. Do not connect the Chamber HV Battery Supplies. Leave the preamplifier input jack open. Connect the pulse attenuators to the amplifier PHS output terminals. Connect the pulse attenuators to the Scaler-Amplifier switch box. Connect the switch box to the scaler input terminals. Leave a-c power off to all equipment.

2. Check that the three Chamber HV battery supplies each have 235 ± 2 vdc open circuit voltage. If the voltage is not within this range, adjust it by manipulating the helipot across the supply battery.

3. Recheck to see that each of the counting channels is consistently labeled; i.e., the preamplifier, amplifier, switch, scaler, timer, and printer should be labeled as Channels 1, 2, or 3.

4. Remove the rear cover of the Channel 1 preamplifier. Turn on the a-c power switch on the Channel 1 amplifier. There is now high voltage on the preamplifier.

5. Check the following operating voltages in the preamplifier:

a) 6.3 ± 0.1 volts ac (rms) on the filament of each tube (pin 4 to chassis). If the voltage is not correct, adjust it with the helipot on the rear of each amplifier chassis.

CAUTION

Do not apply more than 6.5 volts to the filaments.

b) 265 ± 10 volts dc between input connector pin C and chassis.

6. Turn off a-c power to Channel 1 amplifier. Replace bottom cover on preamplifier.

7. Repeat Steps 4, 5, and 6 for Channels 2 and 3.

2. Check of Pulse Operation

8. Turn on a-c power to all amplifiers and scaler-timer-printer units. Allow a 1-hour warmup.

9. Set up the RCL Model 47 Precision Pulser to give 0.5 mv negative pulses. Connect this to the signal input of the Channel 1 preamplifier. Disconnect the signal cable from the amplifier input connector and connect it to the oscilloscope. Negative pulses of 10 ± 2 millivolts should be observed. Reconnect the signal cable to the amplifier.

10. Set the Channel 1 amplifier at BANDWIDTH, 0.5 mc; COARSE GAIN, 64; and FINE GAIN, 1. Set the Function Switch to "USE". Attach a tee connector to the AMPLIFIER OUTPUT, HIGH. Connect a 1000-ohm load resistor to one end of the tee, and connect the scope to the other end of the tee. The observed signal should consist of 60 ± 5 volt positive pulses superimposed on 10-volt peak-to-peak noise.

11. Set the PHS on the Channel 1 amplifier to 35 volts. Connect the scope to the PHS output before the pulse attenuator. The observed signal should consist of 50 ± 10 volt negative pulses of uniform height.

12. Disconnect the cable which feeds pulses to the Channel 1 scaler from the scaler input jack and connect it to the scope. Negative pulses of 0.75 ± 0.25 volts should be observed. Reconnect the signal cable to the scaler input.

13. The pulse rate on the scaler should be 60 counts per second.

14. Repeat Steps 9, 10, 11, 12, and 13 for Pulse Channels 2 and 3.

3. Check of Amplifier and Scaler Resolution Time

15. Disconnect the 50-foot, B+ filament, and signal cable set from the rear of the Channel 1 amplifier.

16. Set the Berkeley Double Pulse Generator (Model 903) to FIRST and SECOND PULSE DURATION, minimum (full counter-clockwise); COARSE FREQUENCY, 1000; FIRST and SECOND PULSES, POSITIVE (+); DOUBLE PULSES. Put a 100-to-1 attenuator on the left hand 1000-ohm output connector. Turn on a-c power to pulser. Connect attenuator to the TEST PULSE INPUT terminal of the Channel 1 amplifier. Turn the amplifier Function Switch to "TEST".

17. Observe the pulses at the AMPLIFIER-HIGH terminal of the amplifier. Adjust the left-hand amplitude adjustment on the Double Pulser until the output pulses observed from the amplifier are positive 55 ± 5 volt pulses.

18. By observing the scaler, check that the pulses are cut off by setting the PHS voltage higher than the pulses observed from the AMPLIFIER-HIGH output.

19. Set the Double Pulse separation at 5 microseconds. Set the PHS at 35 volts. The scaler should now be counting about 2000 counts/sec. Note that only every other light in the right-hand decade is lighted. This is due to the fact that the two pulses are coming very close together and the scaler moves away from every other light so fast that it does not have time to light.

20. Adjust the Double Pulse separation down steadily toward shorter separations until the count rate on the scaler drops by one-half due to the system being unable to resolve the two pulses. When this occurs, every light in the right-hand decade will light. Note the pulse separation at which this occurs. This is the so-called "double pulse" resolution time for the Scaler-Amplifier system and is only approximately the resolution time for random pulses of various heights.

21. Disconnect the Double Pulser from the TEST PULSE input. Return the Function Switch to "USE". Reconnect the 50-foot signal-power cables at the rear of the amplifier chassis.

22. Repeat Steps 15 through 21 for Pulse Channels 2 and 3.

23. Turn off all a-c power to the three counting channels.

B. Alpha Cutoff Measurement

The following test is a check on correct fission chamber operation and is also a measurement of the PHS for which essentially all alpha particle pulses are eliminated.

24. Move all of the Criticality instrumentation, with the exception of the fission chamber stiffeners and sheet metal protective covers, to the auxiliary instrument room. This equipment is listed in Part C of the Appendix.

25. Completely set up all three counting channels.

a) Lay the fission chambers on the floor. Handle them with care. Do not let them bend.

b) Connect the screw-on to snap-on adapters to the fission chambers.

c) Connect the 1-1/2-foot jumper cables to the fission chambers.

d) Put the screw-on to snap-on adapters on the SIGNAL INPUT terminals of the preamplifiers.

e) Connect the signal jumper cable from the chambers, the High Voltage Battery supply, and the 50-foot signal-power cables to the preamplifiers.

f) Lay the preamplifiers on their foam rubber pads and tape the preamplifier and pads to the floor.

g) Erect an exclusion fence around the fission chambers and preamplifiers.

h) Connect the 50-foot signal-power cables to the amplifiers.

i) Set the amplifiers to COARSE GAIN, 64; FINE GAIN, 1; and BANDWIDTH, 0.5 mc. Set the Function Switches to "USE". Connect 1000-ohm load resistors to the AMPLIFIER-HIGH outputs. Attach the pulse attenuators to the PHS outputs.

j) Connect the pulse attenuators to the Scaler-Amplifier Switchbox.

k) Connect the Switchbox to the scalers.

26. Turn on all a-c power and allow a 2-hour warmup.

27. Perform Steps 28 through 31 for each of the three fission chamber channels. This may be done simultaneously.

28. Clear the area inside of the exclusion fence of all personnel for the duration of the test in Step 30.

29. Set the timers for 50 out of 55 seconds. Set the Pulse Height Selectors for 4 volts.

30. Take two 50-second counts at each 2-volt step, starting at 4 volts and ending at 24 volts on the PHS dial. Record the PHS for each count on the printer tape.

31. Plot the data from Step 30 for each chamber on semilog paper as log counts/sec vs PHS volts. Note the value of PHS volts at which the plot shows 1 count/sec. This should be about 18 volts for all three fission chambers.

32. Turn off all a-c power. Disassemble by reversing Step 25. Store equipment.

II. PHYSICAL SETUP FOR CRITICAL TEST

A. Assembly of Fission Chamber Units

Experience has shown that mechanical vibration of the long (20-ft) coaxial transmission lines of these fission chambers causes excessive noise in the pulse circuitry. It has been found that mechanical support, or stiffening, of the chambers will eliminate this effect. Figure I-2 shows the fission chambers assembled to the stiffening assembly. This combination is referred to as the "chamber assembly." The chamber stiffener also provides mechanical protection for the upper cap of the fission chamber.

33. Move the fission chambers and the three stiffener assemblies into the high-bay area. The fission chamber stiffeners are composed of a drilled upper cylinder welded to a long piece of aluminum angle, a threaded spanner-type

hold-down nut, and a drilled brass cylinder. The stiffener assemblies are designed so that the upper cap of the fission chamber fits into the upper portion of the stiffener and the 20-foot tube is cradled in the aluminum angle. The spanner nut presses down on the shoulder of the upper cap of the fission chamber to hold it snugly in the assembly. To afford extra portection, the brass cylinder fits over the electrical connectors after the assembly is complete.

34. Assemble the fission chambers into the stiffener assemblies by sliding the chambers horizontally into the stiffeners. Gently snug the chambers to the aluminum angles, using aluminum wire.

CAUTION

The fission chambers are very fragile. Handle them with care!

Install the spanner nuts and tighten with the special wrench provided. Do not overtighten - one turn is adequate. Install brass cylinders.

B. Loading Fission Chambers into Core

35. Arrange the three fission chamber assemblies on the high-bay floor parallel to one another in an east-west direction. The three top connectors should be in the vicinity of the loading face, and the bottom tips near the storage holes. Install the two eye bolts on the top of each assembly.

36. Using the 5-ton crane, which will be operated by Operations personnel, raise the chamber assemblies one at a time until they are hanging vertically. When the assemblies are raised from the high-bay floor, be very careful that the lower 5 feet of the fission chambers, which extend from the bottom of the stiffener, do not bend or drag on the floor. Install the assemblies in the reactor by lowering them into the instrument thimbles in R-4, R-65, and R-71. Experimental Unit personnel shall perform all of this loading operation with the exception of the crane operation.

C. Setup of Electronic Equipment

37. Remove the brass cylinders. Install the screw-on to snap-on adapters on the chambers. Install the 1-1/2-foot jumper cables to the chambers. Replace the brass cylinder.

38. Complete the electronic setup, following the sequence in Step 25d through k with the exception that the preamplifier, on its foam rubber pad, should not as yet be taped down. The 50-foot cables are to be fed through the pull hole in the Sanborn Room wall to connect to the amplifiers which will be located in the Sanborn Room (see Figure I-1). The pull hole must be sealed after pulling the cables. Tape the 50-foot cables to the loading face and floor to prevent the possibility of anyone tripping over them.

39. Install a rope exclusion fence around the ring shield. Clear this area of all except Experimental Unit personnel.

40. Connect the special safety circuit into the Scaler-Amplifier Switch-box.

III. FINAL SYSTEM TEST

A. Check of System Operating Voltages

41. On the loading face, carefully open the three preamplifiers by removing the bottom covers.

42. Turn on a-c power to the amplifiers. Allow a 15-minute warmup period.

43. Perform Step 5 for each preamplifier.

44. Check that there is 235 ± 2 vdc between the input HV pin and the chassis on each preamplifier. Any drift observed from the results found in Step 2 may indicate faulty batteries.

45. Turn off a-c power to the amplifiers. Replace the bottom covers on the preamplifiers. Tape the preamplifiers and their foam rubber pads to the loading face. Install the chamber protective covers and tape them down.

B. Pulse Height Inspection

46. Turn on a-c power to all equipment except the printers. Allow a 4-hour warmup period. In case of loss of a-c power during any of the tests, allow a 1-hour warmup period for each minute of loss of a-c power (up to the full 4 hours) before resuming counting measurements.

47. Set the PHS settings on all three amplifiers at 35 volts. (Amplifiers should have COARSE GAIN, 64; FINE GAIN, 1; BANDWIDTH 0.5; FUNCTION SWITCH, "USE".)

48. Clear the loading face area of all personnel. No one should walk on the loading face or within the exclusion fence during the remaining tests in this procedure. These tests will take about 12 hours.

WARNING

NO FUEL SHOULD BE IN THE REACTOR

49. Pull all control rods (shim and safety). Using a Tektronix Oscilloscope Model 535, or equivalent, inspect the shape of the "neutron" and alpha pulses at the AMPLIFIER OUTPUT terminal of each of the three channels. The pulses should be very similar in height and shape to those shown in Figure I-3.

50. Photograph, or record in digital form, the actual pulse shapes observed on the oscilloscope for each channel. If the pulse shapes observed do not correspond very closely to those shown in Figure I-3, suspend further testing.

C. PHS Calibration Check

Past experiments have shown that the optimum PHS setting for the WX 4110 fission chambers with the above amplifier settings is 35 volts. A quick check on this may be made by examining the relative heights of the "neutron" and alpha pulses at the AID amplifier output.

51. In the same manner as Step 49, examine the relative heights of the "neutron" and alpha pulses at the AID AMPLIFIER OUTPUT terminals. The pulses should look like those in Figure I-3 with 35 volts falling above the tops of the alpha pulses and below the tops of the "neutron" pulses.

52. If the 35-volt setting does not fall between the alpha and "neutron" pulses, recheck the gain settings as specified in Step 25i. If the pulses are still of the wrong size, a malfunction probably exists in the amplifiers.

D. Analysis for Counting Noise and Unusual Statistics

53. Set the counting times on the scaler-timers to obtain 5000 to 6000 counts per interval (50 to 60 minutes). Take ten counts on each of the three channels. Select the highest count and lowest count from each group. Call these C_h and C_ℓ. Compute the count rates for each pair of counts by dividing by t_c, the counting time:

$$r_h = \frac{C_h}{t_c} \qquad \ldots (1)$$

$$r_\ell = \frac{C_\ell}{t_c} \qquad \ldots (2)$$

54. Compute the standard error of the difference of each pair of counting rates:*

$$\sigma = \left(\frac{r_h + r_\ell}{t_c} \right)^{1/2} \qquad \ldots (3)$$

If the equipment is not counting spurious counts, then the absolute value of the difference in the count rates should be less than 1.6 times the value of σ as defined by Equation 3:

$$(r_h - r_\ell) \leq (1.6)\sigma^\dagger \qquad \ldots (4)$$

55. Proceed with Step 5 of the Critical Loading Experiment.

*W. J. Price, Nuclear Radiation Detection, (New York: McGraw Hill Book Co., 1958), p 61-62

†Only about 5% probability of exceeding this with normal statistics.

APPENDIX

A. SCHEDULE

Part I is to begin as soon as possible and is complete in itself. Parts II and III will be done as Step 4 of the Critical Loading Experiment. The experiment should require one day for completion.

B. MANPOWER REQUIREMENTS

Regular operating crew

1 engineer and 1 technician from the Experimental Unit (each shift).

1 additional engineer and technician (as required).

C. EQUIPMENT REQUIREMENTS

1. Laboratory Equipment

   1 Tektronix Model 535 Oscilloscope

   1 RCL Model 47 Precision Pulser

   1 Berkeley Model 903 Double Pulse Generator

2. Criticality Instrumentation

   Loading Face Area

   3 WX 4110 Westinghouse Flux Mapping Fission Chambers

   3 Fission Chamber Stiffening Assemblies including supply of aluminum wire and hold-down nuts

   9 Coaxial adapter connectors for fission chamber output connectors, preamplifier signal input connectors, and fission chamber HV connectors on preamplifier—male screw-on type to male snap-on type

   3 1-1/2-ft jumper cables—chambers to preamplifiers—female snap-on connectors on both ends

3 High Voltage Supply Battery Sets adjustable to 235 volts for Chamber HV — output to be on 1-1/2-foot coaxial cable with female snap-on connector on output end

3 Red and white sheet metal Chamber Protective Covers

3 Preamplifiers (BA219B) modified to Cathode Follower Outputs

3 50-ft sets of shielded cables to supply B+ and filament power to the preamplifiers and carry the signal return. The signal cable is the separate shielded cable.

Sanborn Room Area

1 Sanborn Room Cable Pull Box (north wall)

3 Linear Pulse Amplifiers (BA218) with filament power output modified to feed 6.3 volts ac (rms) to filaments at the end of the 50-foot cables

3 1 k ohm load resistor assemblies to provide termination on AMPLIFIER HIGH outputs

3 Pulse attenuators to attenuate output of PHS — must match 1 megohm output impedance and step down variable from 40-to-1 to 60-to-1 — to deliver 1-volt pulses to counter

3 2-ft coaxial cables — female snap-on connectors on both ends to connect attenuated PHS output to scaler-amplifier switch box

3 3-ft coaxial cables — female snap-on connectors on both ends to connect scaler-amplifier switch box to scalers

1 Scaler-Amplifier Switch Box to connect each scaler and the special safety channel to any one of the amplifier PHS outputs

3 Scaler-Timer-Printer units equivalent to Beckman-Berkeley System

D. CREDIBLE ACCIDENT

Since there will be no fuel in the reactor during this test, there is no nuclear hazard.

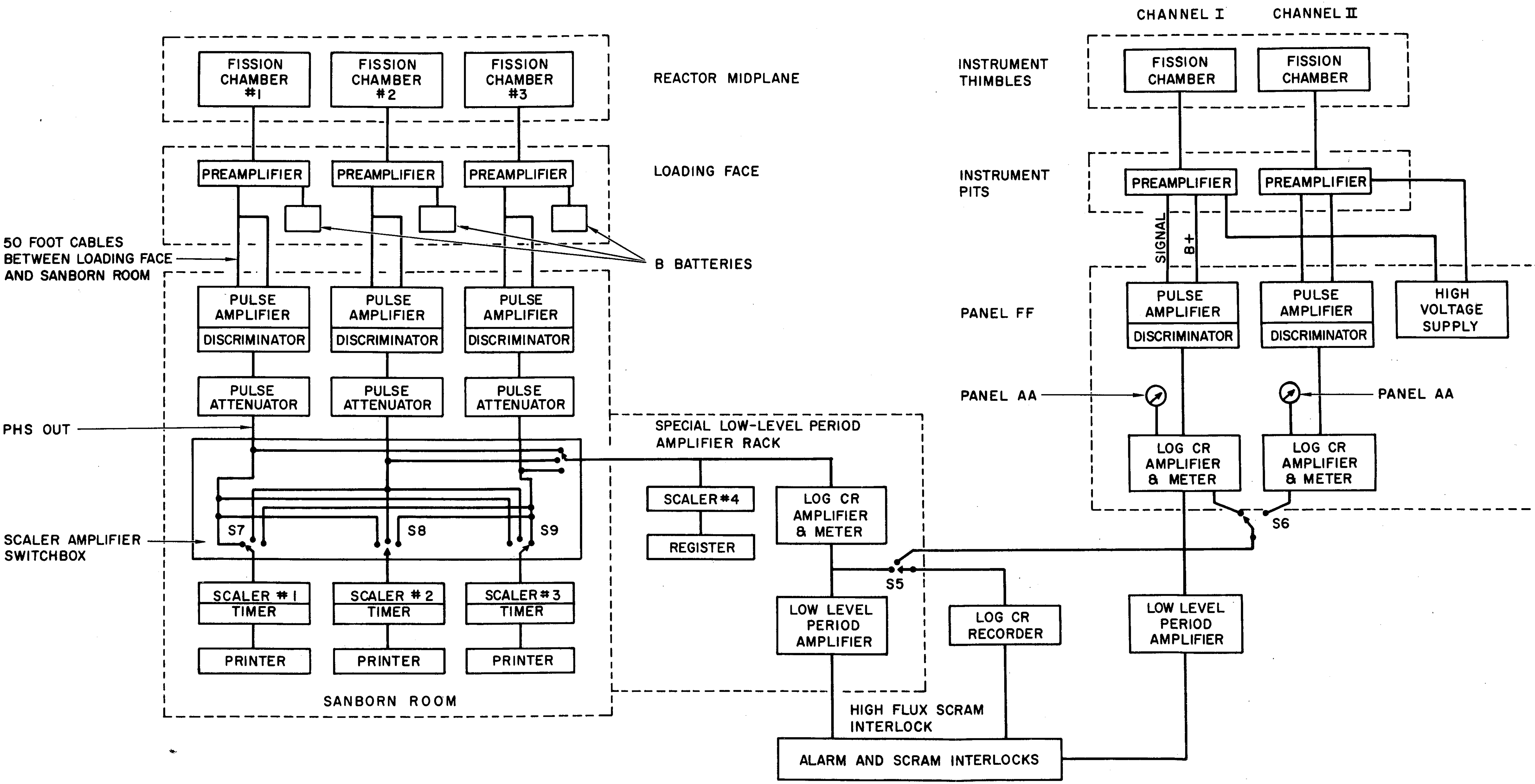

Figure I-1. Instrumentation for Critical Test

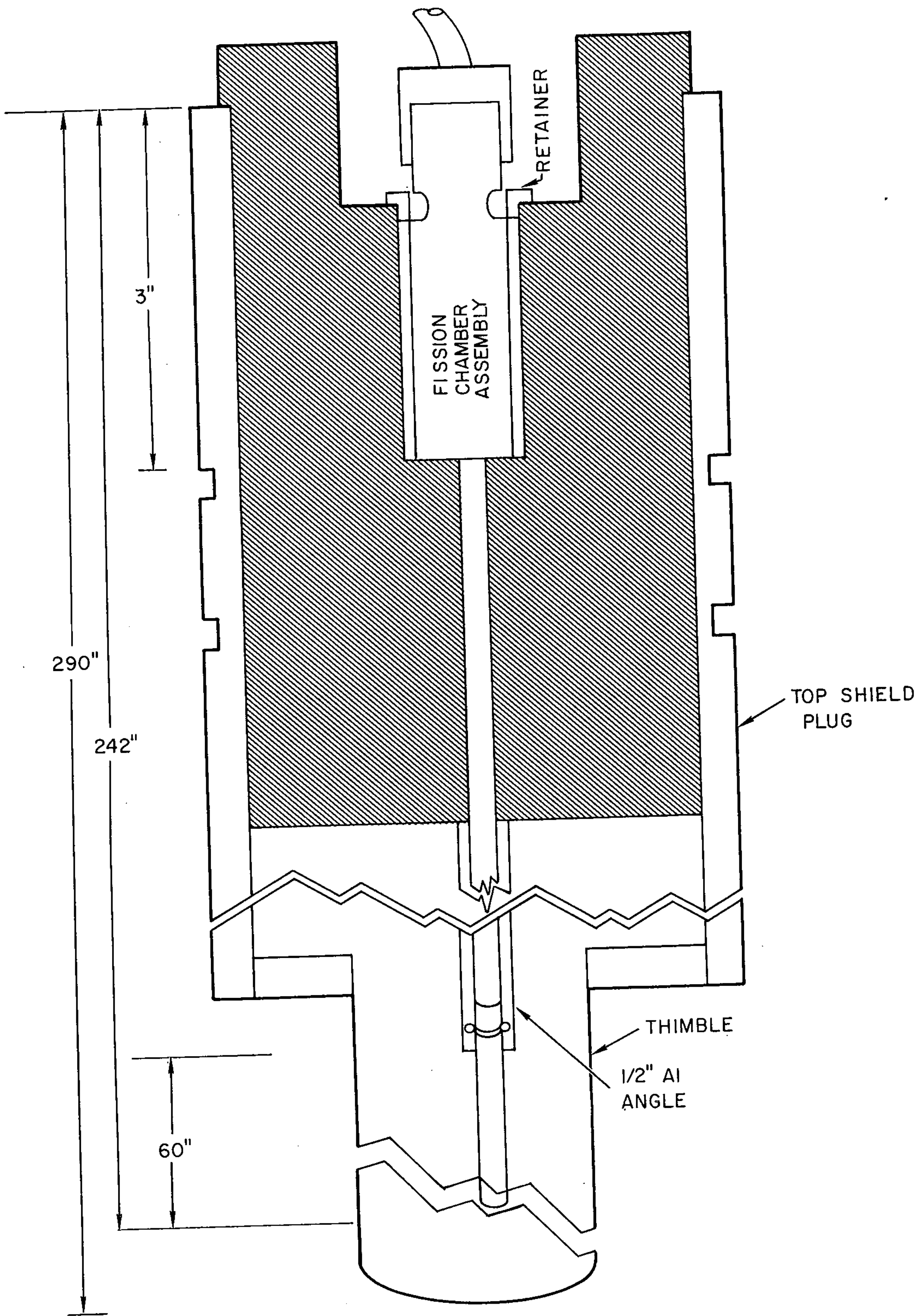

Figure I-2. Fission Chamber Stiffener Assembly

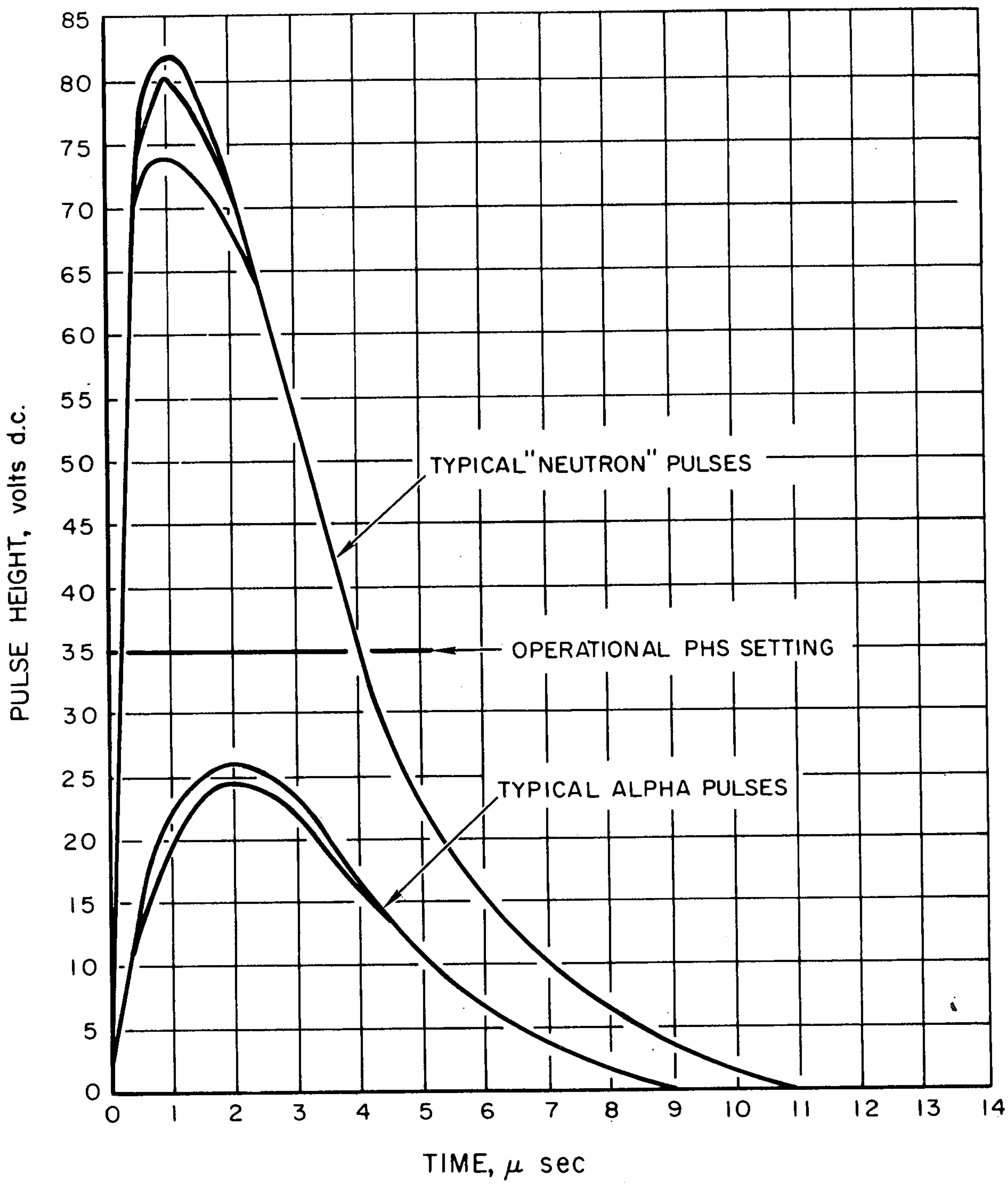

Figure I-3. Typical "Neutron" and Alpha Pulse Shapes at AID Amplifier Output from WX4110 Fission Chambers (Bandwidth = 0.5 Mc. Full Gain)

II

CRITICAL LOADING EXPERIMENT

By

R. W. WOODRUFF

CONTENTS

FIGURES

TABLES

OBJECTIVE

This experiment will determine the number of five-rod, 7.1 wt % U^{235}, thorium-uranium clusters required for SRE criticality for two cases: one with all the control rods withdrawn and the other with only shim rods 3 and 4 inserted.

PURPOSE

The principal purpose of this experiment is to safely obtain an operational thorium-uranium fuel loading for the SRE. The loading will have an excess reactivity equal to that absorbed by shim rods 3 and 4, which is approximately five dollars, as specified in the Hazards Summary.[1] In addition, the measurements of the two critical loadings will be used in the evaluation of calculational techniques. These will include calculations of critical size from first principles as well as estimates based on measurements in the SRE with the enriched uranium loading[2] and in the SGR Critical Facility with the five- and seven-rod thorium-uranium clusters.

METHOD

The multiplication will be measured with three fission chambers symmetrically placed in the reflector, and its inverse will be plotted as a function of the effective radius of the core. The curve will approach zero as the loading approaches criticality. This procedure[3,4,5,6] was previously applied at the SRE for determining the minimum wet and dry critical loadings with enriched uranium, except that the data were plotted as a function of the square of the effective radius, i.e. as a function of the number of clusters loaded. Results for that experiment, plotting the data both ways, are shown in Figure II-1.

In the present application, three inverse multiplication curves will be obtained concurrently during fuel loading: the first with all the control rods withdrawn, the second with only shim rods 3 and 4 inserted, and the third with all the shim rods inserted. The first curve will establish the minimum critical loading; the second, the operational loading; and the third will provide an extra margin of safety. During each loading operation, at least two safety rods will always be withdrawn and their scram circuits will be energized. After each loading operation, the data will be analyzed before another cluster is inserted. No additional clusters will be inserted after the operational loading is obtained.

PROCEDURE

In Steps 1 through 14, the reactor will be loaded in preparation for the criticality experiment. The counting rate for each fission chamber will be measured for three different shim configurations with the source but no fuel in the reactor. The measured rates will be used in normalizing later data.

1.(O) Fill the primary sodium system. Set the flow for 1000 gpm, and maintain it constant as indicated on the primary flowmeter during all count rate measurements. During loading operations, reduce flow to 300 gpm in accordance with Standard Operating Procedure 9.

2.(O) Load the reactor as shown in Figure II-2 and connect the control rod drives.

See Addendum I → 3.(O) Connect the pool heater in Channel 59 to the 480-volt a-c bus through a Variac, or the equivalent. Use the pool and line heaters to adjust the average of the inlet and outlet primary sodium temperatures, as indicated on the process instrumentation, to 340°F. If necessary, connect additional pool heaters to the bus.

4.(O,E) Complete the work required in Parts II and III of Experiment I.

5.(E) Should there be a power loss at any time to the special instrumentation (see Figure II-3), allow a 30-minute warmup.

See Addendum I → 6.(E) Should it be necessary to disconnect the preamplifiers from the high-voltage supply for any reason, first ~~open the disconnect switches shown in Figure II-3.~~ ~~Set the switch on the battery supply to "off."~~

See Addendum I → 7.(O) Allow no one on the loading face during Steps 8 through 14 without permission from the Experimental Unit Engineer.

8. (E) Make certain that flux equilibrium exists as indicated by the log count rate recorder (see Figure II-3). This will become increasingly important as k_{eff} approaches unity later in the experiment.

See Addendum 1 → 9. (E) Set the counting interval on the scalers in Channels 1, 2, and 3 to obtain approximately 10^4 counts. Record the requisite information on a data sheet having the format displayed in Figure II-4.

10. (E) Calculate the measured counting rate for each chamber by dividing the observed number of counts by the counting interval. Calculate the corrected counting rate from $D = C/(1 - \tau C)$ where C is the measured counting rate and τ is the resolution time for the circuitry.

11. (O) Insert shim rods 3 and 4.

See Addendum 1 → 12. (E) Repeat Steps 8, 9, and 10.

13. (O) Insert shim rods 1 and 2.

See Addendum 1 → 14. (E) Repeat Steps 8, 9, and 10.

15. (E) Prepare a graph having the format shown in Figure II-5. Plot the point (0,1), which will be common to the three curves to be generated.

16. (O,S) Test the scram systems described in Section C of the Appendix.

See Addendum 1 → 17. (O S) Place the fission chambers in Instrument Channels I and II at the bottom of their thimbles. Place the compensated ion chamber which provides the signal for the log N recorder at the bottom of its thimble.

18. (O,S) Do not bypass the scram circuitry described in Section C of the Appendix during the remainder of the experiment. Should defects in the circuitry occur, insert all control rods and repair them before proceeding.

Steps 19 through 29 will be repeated successively, loading fuel one to four clusters per sequence. The average multiplication of the lattice will be measured during each sequence for one to three shim configurations as required by Table II-I. The inverse multiplication curve for each shim configuration will then be plotted and extrapolated as each new datum becomes available. The curves for all shim rods withdrawn and for shim rods 3 and 4 inserted will be extrapolated to zero to determine the minimum critical and operational loadings. The curve for all shim rods inserted will be extrapolated to the loading for the next repetition of Steps 19 through 29 to demonstrate that the reactor will be subcritical with the shim rods in and the safety rods out. This portion of the procedure will be repeated until the extrapolated inverse multiplication curve indicates that the insertion of two to three more clusters would make the reactor critical with all control rods withdrawn.

See Addendum 1 →19. (O) Prepare to load fuel for the next set of count rate measurements as specified in Table II-1 and Figure II-6. Insert those safety rods whose drives must be removed to provide access for the gas lock to the fuel channels to be loaded. At least two safety rods and preferably all of them must remain withdrawn with their scram circuitry energized.

20. (O) Do not bump or disturb the fission chambers, preamplifiers, or their cables. Remove the control rod drives which interfere with loading. Load fuel after receiving the express and prior approval of both the Shift Supervisor and the Experimental Unit Engineer. An Experimental Unit Representative will be at the loading face during this operation. Replace the control rod drives. Connect the fuel-channel exit temperature thermocouples in Channels 33, 34, and 44 to the scram interlocks as soon as these channels are loaded.

See Addendum 1 →21. (O,E) Constantly monitor either Chambers 1, 2, or 3 on the log count rate recorder during the following fuel loading or control rod withdrawal until the flux reaches equilibrium. If the reactor sustains a positive asymptotic period as indicated by a straight line on the recorder, insert the control rods and obtain instructions from R. E. Durand and R. W. Woodruff before proceeding. Just before the count rate goes off scale on the log count rate recorder, connect it to the regular low-level startup channel, using switch S5 (see Figure II-3).

22. (O) Withdraw the safety rods after receiving approval from both the Shift Supervisor and the Experimental Unit Engineer.

23. (O,E) Repeat Step 21.

See Addendum 1 →24. (E) Repeat Steps 9 and 10. Calculate the multiplication for each chamber by dividing the corrected count rate for this shim rod and fuel configuration by the corrected count rate for the same shim rod configuration with no fuel in the reactor. Calculate the average of the multiplications measured with each chamber. Calculate the inverse of the average.

TABLE II-1

SEQUENCE FOR LOADING TO MINIMUM CRITICALITY

Number of Clusters Loaded	Last Channel Loaded	Cluster Identification	Multiplication Measurements		
			All Shim Rods In	Shim Rods 1 and 2 Out	All Shim Rods Out
0	-		X	X	X
1	44	SU-22-11†			
2	33	-14†	X		X
3	34	-36			
4	43	-34	X		X
5	45	-16			
6	55	-39			
7	56	-15	X	X	X
8	22	-18			
9	32	-19			
10	54	-20			
11	35	-10†	X		X
12	57	-21			
13	68	-13†			
14	21	-12†	X	X	X
15	42	-42 or - 8†			
16	23	-25			
17	46	-38	X		X
18	67	-17			
19	69	- 7†	X		X
20	10	-26			
21	11	-27	X	X	X
22	20	-24			
23	31	-28 or - 5†	X		X
24*	53	-30	X		X
25*	66	- 4†	X	X	X
26*	24	- 9†	X		X
27*	36	-29	X		X
28*	58	-33	X		X

*Estimated minimum critical loading
†Thermocoupled cluster

25. (E) Plot the inverse on the graph prepared in Step 15. Extend the appropriate curve through this point. Extrapolate the curve with all shim rods in to the next fuel loading required for measurements as shown in Table II-1. Extrapolate the curves for shim rods partially or completely withdrawn to zero.

26. (O) If a multiplication measurement is required by Table II-1 with shim rods 1 and 2 withdrawn, make the withdrawal after obtaining approval from both the Shift Supervisor and the Experimental Unit Engineer.

27. (O,E) Repeat Steps 21, 24, and 25.

28. (O) If a multiplication measurement is required by Table II-1 with all the shim rods withdrawn, make the withdrawal after obtaining approval from both the Shift Supervisor and the Experimental Unit Engineer.

29. (O,E) Repeat Steps 21, 24, and 25.

30. (O,E) After analyzing the data, but before loading the next group of fuel clusters specified in Table II-1, the Shift Supervisor and the Experimental Unit Engineer should sign an entry in the Operations Log approving the loading of these clusters. Repeat Steps 19 through 29* until the extrapolation of the inverse multiplication curve with all shim rods withdrawn indicates that loading two to three clusters will make the reactor critical. If criticality with the shim rods withdrawn is not attained after loading 28 clusters, suspend loading operations until the situation is re-evaluated and the Ad Hoc Committee is so advised.

In Steps 31 through 35, an additional cluster will be loaded, and the multiplication measurements will proceed as before except that the withdrawal of shim rods 3 and 4 will be performed incrementally. Loading will continue one cluster at a time until the next cluster would make the reactor supercritical with all the shim rods withdrawn. At this point the inverse multiplication curve for all shim rods out will be extrapolated to zero to obtain the final estimate of the minimum critical loading.

31. (E) Prepare another graph similar to Figure II-5 using a larger scale. Plot the last few data points and also the data points to be obtained in Steps 32 through 35.

32. (O,E) Repeat Steps 19 through 27.*

~~*[illegible] dummy [illegible] place [illegible] 2, [illegible] the special dummy from channel to [illegible] put it in the [illegible] then remove the dummy from channel [illegible] place it [illegible] to [illegible]~~

33. (O) Obtain permission from the Shift Supervisor and the Experimental Unit Engineer to withdraw shim rods 3 and 4. Perform the withdrawal incrementally as follows: (a) withdraw shim rod 4 to 36 in. out and then to the upper limit switch; and (b) withdraw shim rod 3 to 26, 38, and 49 in. out and then to the upper limit switch. Wait after each withdrawal for the flux to reach equilibrium as indicated on the log count rate recorder. Should the reactor sustain a positive asymptotic period as indicated by a straight line on the recorder, adjust the shims for constant flux, record their positions, insert all the shims, and proceed to Step 37.

34. (O,E) Repeat Steps 24 and 25.

35. (O,E) After analyzing the data but before loading the next fuel cluster specified in Table II-1, the Shift Supervisor and Experimental Unit Engineer will sign an entry in the Operations Log approving the loading of this cluster. Repeat Steps 32, 33, and 34 until extrapolation of the inverse multiplication curve with all shim rods withdrawn indicates that loading one more cluster would make the reactor supercritical. The last extrapolation will provide the final estimate of the minimum critical loading. If criticality with all shim rods withdrawn is not attained with 28 clusters loaded, suspend loading operations until the situation is re-evaluated and the Ad Hoc Committee is so advised.

See Addendum 1 → 36. (O) Load zircaloy thimbles containing graphite sleeves in Channels 50 and 60. Load a neutron-sensitive thermopile in each thimble. These will be used for detecting flux changes in subsequent experiments. Load the paraffin-cadmium-lead shield plugs in each thimble.

In Step 37, the reactor will be loaded to within two to three clusters of the operational loading.

37. Repeat Steps 19 through 30,* except for Steps 28 and 29. Substitute "Table II-2" for "Table II-1" in Steps 19, 26, and 30. In Step 30 substitute "shim rods 1 and 2" for "all shim rods" and "35 clusters" for "28 clusters".

The operational loading will be completed in Steps 38 through 43. One cluster will be inserted at a time, and shim rods 1 and 2 will be withdrawn in increments.

~~measurements with all shim rods in, and with shim rods 1 and 2 [illegible]~~

~~c) Insert a dummy element into channel 2, and replace the special dummy element in channel [illegible] with a standard element.~~

~~d) Without adding another fuel assembly, repeat both multiplication measurements.~~

~~e) Continue with the main procedure.~~

TABLE II-2

SEQUENCE FOR LOADING TO THE OPERATIONAL FUEL CONFIGURATION

Number of Clusters Loaded	Last Channel Loaded	Cluster Identification	Multiplication Measurements: All Shim Rods In	Multiplication Measurements: Shim Rods 1 and 2 Out
25	66	SU-22- 4†	**	**
26	24	- 9†	X	X
27	36	-29		
28	58	-33	X	X
29	70	-40		
30	75	-31	X	X
31*	74	-37	X	X
32*	41	-41	X	X
33*	9	-22	X	X
34*	12	-23 or - 3†	X	X
35*	73	-32 or - 6†	X	X

*Estimated Operational Loading
†Thermocoupled Cluster
~~** See Note starting on page II-7.~~

38. (E) Prepare another graph similar to Figure II-5 using a larger scale. Plot the last few data points with all shim rods inserted and with shim rods 1 and 2 withdrawn and also the data points to be obtained below.

39. (O,E) Repeat Steps 19 through 25. Substitute "Table II-2" for "Table II-1" in Step 19.

40. (O) Repeat Step 33 substituting "shim rods 1 and 2" for "shim rods 3 and 4", "shim rod 2" for "shim rod 4", and "shim rod 1" for "shim rod 3". Substitute "Step 43" for "Step 37".

41. (O,E) Repeat Steps 24 and 25.

42. (O, E) After analyzing the data but before loading the next fuel cluster specified in Table II-2, the Shift Supervisor and the Experimental Unit Engineer will sign an entry in the Operations Log approving the loading of the

next cluster. Repeat Steps 39, 40, and 41 until extrapolation of the inverse multiplication curve with shim rods 3 and 4 inserted indicates that loading one more cluster would make the reactor supercritical. If criticality with shim rods 3 and 4 inserted is not attained with 35 clusters loaded, suspend loading operations until the situation is re-evaluated and the Ad Hoc Committee is so advised.

See Addendum I → 43. (O,E) The operational loading is completed. Insert the shim rods and ~~leave~~ the safety rods ~~out~~.

See Addendum I → 44. (O,S) Connect all the fuel cluster and fuel channel thermocouples to their recorders.

See Addendum I → 45. (O, E) Proceed to the next experiment.

EXPECTED RESULTS

An estimate based on measurements in the enriched uranium SRE loading[2] and in the SGR Critical Facility gives 26 ± 2 clusters for the minimum critical loading. A similar estimate yields 33 ± 2 clusters for the operational loading, i.e. for the critical loading with shim rods 1 and 2 out and 3 and 4 in. The latter estimate required the worth of shim rods 3 and 4, which will be essentially the same for this fuel loading as it was for the enriched uranium loading.[1]

EXPECTED CONCLUSIONS

The operational thorium-uranium loading will determine the magnitude of the Xe^{135} reactivity transient. At 20 Mw with equilibrium Xe^{135}, the reactivity absorbed will be as follows:

Number of Clusters	Reactivity Absorbed by Xe^{135} (dollars)
30	2.9
35	2.7
40	2.4

These results were obtained by applying the method demonstrated for the enriched uranium loading.[7] Assuming that the minimum critical loading is 26 ~~± 2~~ clusters, and that the operational loading is 33 clusters, the excess reactivity at full power will be as follows:

Number of Clusters	Excess Reactivity (dollars)
31	0.9 ± 0.8
33	2.3 ± 0.8
35	3.6 ± 0.8

This includes the cold, clean reactivity, the effects of equilibrium Xe^{135}, and the isothermal temperature coefficient,[1] but it neglects the effect of the power coefficient, which, however, is small.

For first core, estimated source strength was $6 \cdot 10^7$ neutrons/sec (25 curies of Sb-124) which gave 200 to 300 cpm with all control out or 100 cpm with shims in.

For second core ~~at the~~ (Aug. 1, 1960), the estimated strength was $3 \cdot 10^7$ neutrons/sec. This was 2 half lives below delivery strength.

APPENDIX

A. SCHEDULE

Loading the reactor in accordance with Figure II-2 and instrumentation testing will each require approximately one day. Fuel loading will then be performed. The time required to remove the necessary control drives, load a cluster, replace the drives, count for three different shim configurations, and insert the shim rods is estimated to be five hours. Where one less counting procedure is required, this time is reduced by one hour. On this basis, the time necessary for loading fuel and counting is five days, which gives a total of 7 days for the experiment.

B. MANPOWER REQUIREMENTS

The Experimental Unit will supply one Performance Evaluation Engineer and an assistant per shift to conduct the experiment, and the SRE Operations Unit will provide the Shift Supervisors and normal working crews. The Experimental Unit will operate the counters, disconnect and handle the preamplifiers, and prepare the criticality predictions. Operations will load fuel and operate the reactor.

C. EQUIPMENT REQUIREMENTS

An Sb-Be source, which is a duplicate of the one previously used in the SRE, will be used for this experiment, provided that it can be activated at the MTR without delaying the startup schedule. Its strength will be 10^9 neutrons/sec on delivery, which will give a counting rate of ~~200~~ 400 to ~~300~~ 600 cpm at the detectors with the shim rods out or ~~100~~ 200 cpm with the shim rods in. If the source cannot be activated by the time it is needed, a substitute Po-Be source, which will have a minimum strength of 10^8 neutrons/sec, will be used.

The four fission chambers having sensitivities of 10^{-3} cps per nv were purchased especially for this experiment. The chambers have high-temperature leads and are designed so that they can be positioned at the reactor midplane. All three have been tested, and one of them was used in detecting ruptured moderator cans. This experience indicated that the chambers should be strengthened with aluminum angles fastened along their length to prevent flexing. Each chamber will be individually instrumented as shown in Figure II-2.

See Addendum 1

Eight pool heaters capable of generating 10 kw each will be installed in peripheral channels as indicated in Figure II-2, primarily for heating the sodium during the later experiment to measure the isothermal temperature coefficient (Experiment X). The heaters will be used as required during this experiment to heat the sodium initially and to maintain constant temperature. They will be connected in parallel through switching and connector panels to the 480-volt a-c bus. The heater in Channel 59 will be connected in series with a Variac so that its output can be changed at will.

During the experiment, five scram circuits will always be connected to the safety amplifier which controls the safety-rod holding magnets.[8] The low-level period amplifier shown in Figure II-3 will initiate a scram when the period is less than four seconds. This circuit will be operative until the amplifier saturates. At 0.0001% of full power, i.e. at 20 watts, the high-level period amplifiers in Instrument Channels III and IV will become effective. These amplifiers

TABLE II-3

COMPONENTS

35 or more	Five-Rod Fuel Clusters
~~18~~ 17	Center-Channel Dummies
6	Corner-Channel Dummies
8 (See Addendum 1)	Pool Heaters
8	Blind Plugs
4	Shim Rods
4	Safety Rods
3	Fission Chambers
3	Stainless-Steel Thimbles
2	Sodium-Level Probes
2	Beryllium-Temperature Probes
1	Neutron Source

are part of the normal safety circuitry and will ring an alarm at 20 seconds, initiate an automatic insertion of the shim rods at 10 seconds, and scram the reactor at 5 seconds. The log count rate recorder will scram the reactor at 10,000 cps. It will be connected to Fission Chambers 1, 2, or 3. If the counting rate approaches the set-point, the recorder will be switched to either Instrument Channel I or II which will, in effect, raise the set-point. The flux safety channels, i.e. Instrument Channels V and VI, will be modified to scram the reactor at 0.1% of full power. Three fuel-channel exit temperatures will be monitored. If two of them exceed 390°F, the reactor will be automatically scrammed. None of these circuits may be bypassed after fuel loading commences.

The components listed in Table II-3 are required for the experiments.

D. CREDIBLE ACCIDENTS

The possibility of the reactor becoming supercritical during loading is small because of the extrapolation of the inverse multiplication curve with all the shim rods inserted. Should this occur, those safety rods which are withdrawn will be dropped either by a manual or automatic scram. Two to four safety rods will always be withdrawn during loading, and the scram circuitry described above will be operational.

The paraffin-cadmium-lead shield plugs in Channels 50 and 60 were designed to reduce the fast- and slow-neutron and gamma radiations to tolerance levels at the loading face with the reactor operating at 20 kw. Where 20 kw is exceeded during the subsequent experiments, monitoring services by Health Physics will be required.

REFERENCES

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3. R. W. Campbell, "Low-Power Physics Experiments on the Sodium Reactor Experiment," NAA-SR-3341, June 15, 1959

4. R. D. Burch and J. E. Owens, "SRE Room Temperature Sub-Critical Test," NAA-SR-Memo 1865, March 7, 1957

5. C. Guderjahn, "Some Nuclear Experiments on the SRE," NAA-SR-Memo 1956, June 5, 1957

6. C. Guderjahn, "SRE Critical and Low Flux Experiments," NAA-SR-Memo 1838, February 1, 1957

7. R. W. Woodruff, "Reactivity Absorbed by Xenon-135 in the SRE," NAA-SR-4328, January 28, 1960

8. R. J. Hall, "SRE Instrumentation and Control," NAA-SR-Memo 1639

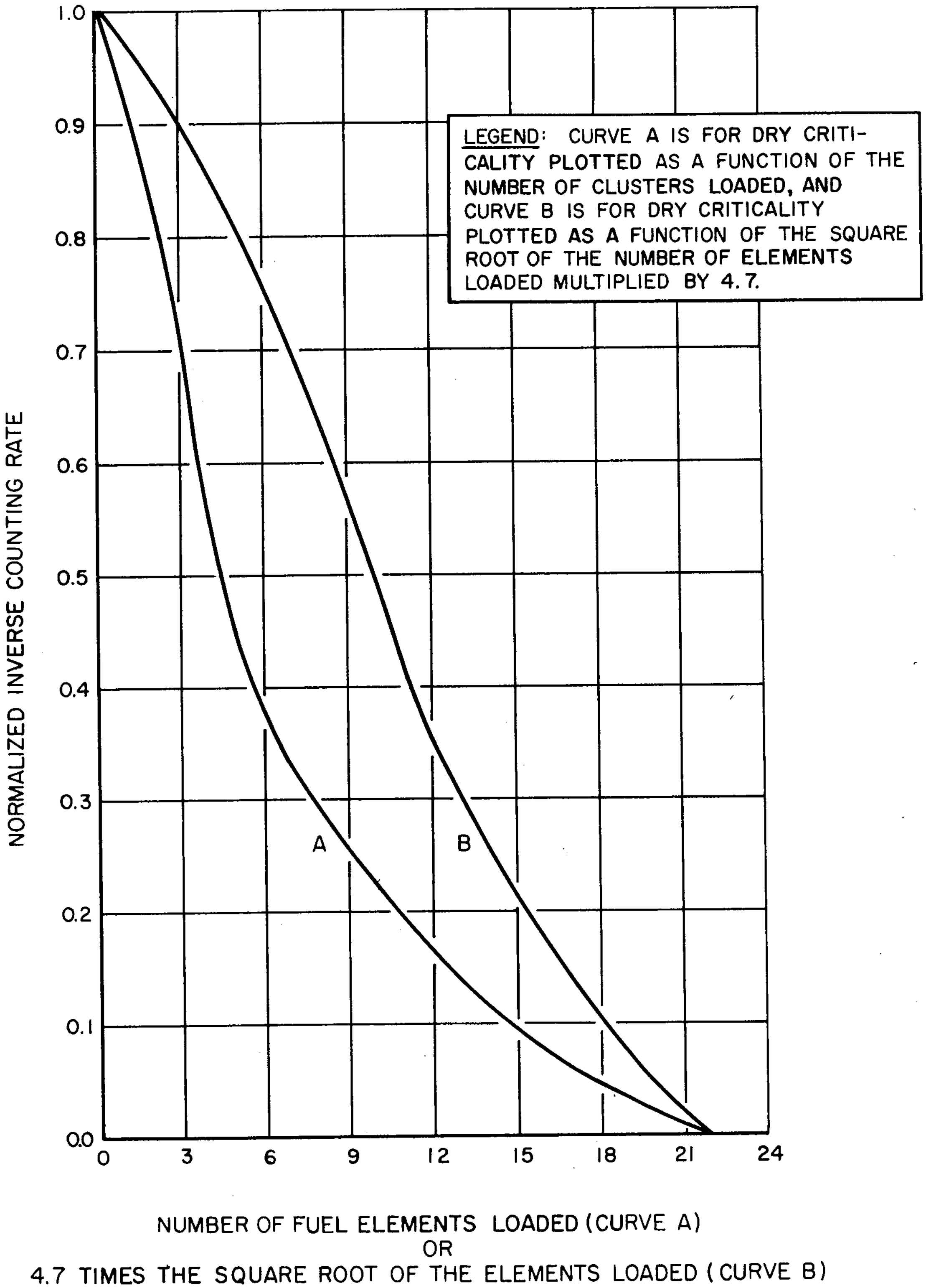


Figure II-1. Inverse Multiplication Curves for Enriched Uranium Loading

See Addendum 1

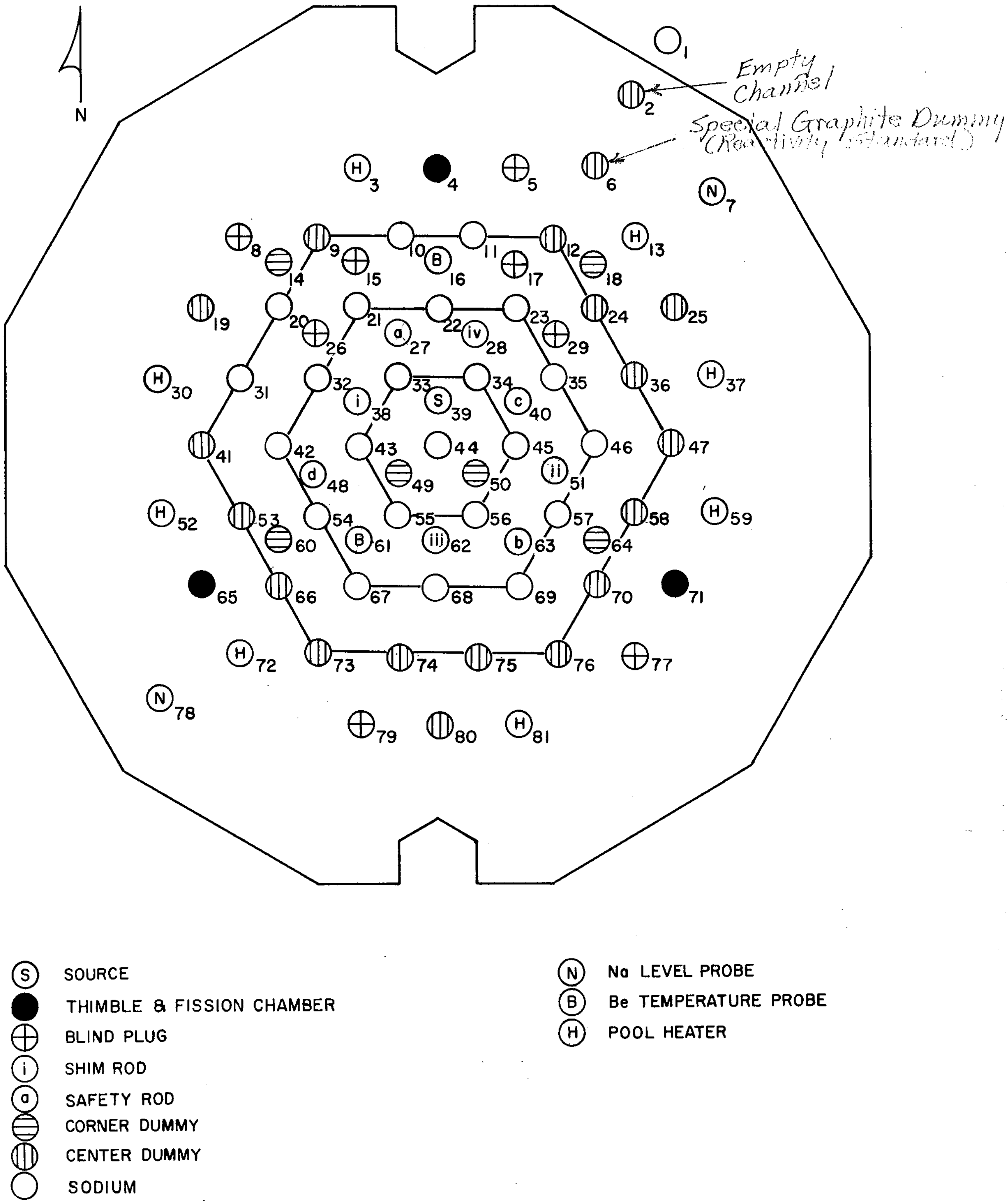


Figure II-2. Initial Core Loading

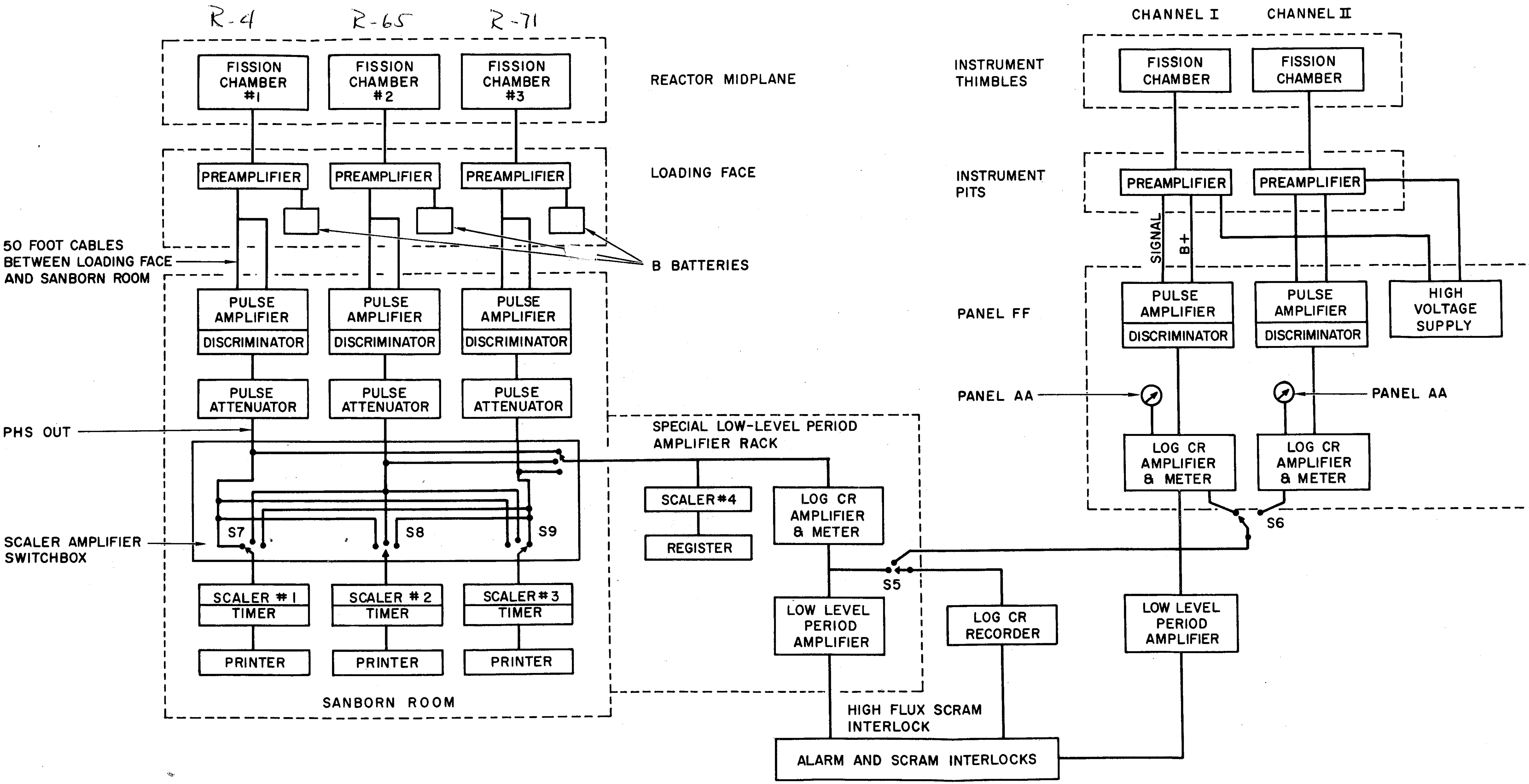


Figure II-3. Instrumentation for Critical Experiment

See Addendum 1

Number, N, of Clusters Loaded		0	0	0	2	2	4	4	7	7	7	11	11	21	21
Channel for Last Cluster		-	-	-	33	33	43	43	56	56	56	35	35	14	14
Shim rod Configuration*		a	b	c	a	c	a	c	a	b	c	a	c	a	b
Date															
Clock Time															
Average Sodium Temperature (°F)															
Time Interval (seconds)															
Number of Counts	1†														
	2														
	3														
Measured Counting Rate	1														
	2														
	3														
Corrected Counting Rate	1														
	2														
	3														
Multiplication	1														
	2														
	3														
	Avg.														
Inverse Multiplication															
$1.52\sqrt{N}$															

*a. All shim rods in
b. Shim rods 1 and 2 out
c. All shim rods out

†Fission chamber number (q.v. Figure 3)

$\tau_1 =$
$\tau_2 =$
$\tau_3 =$

Figure II-4. Data Sheet Format

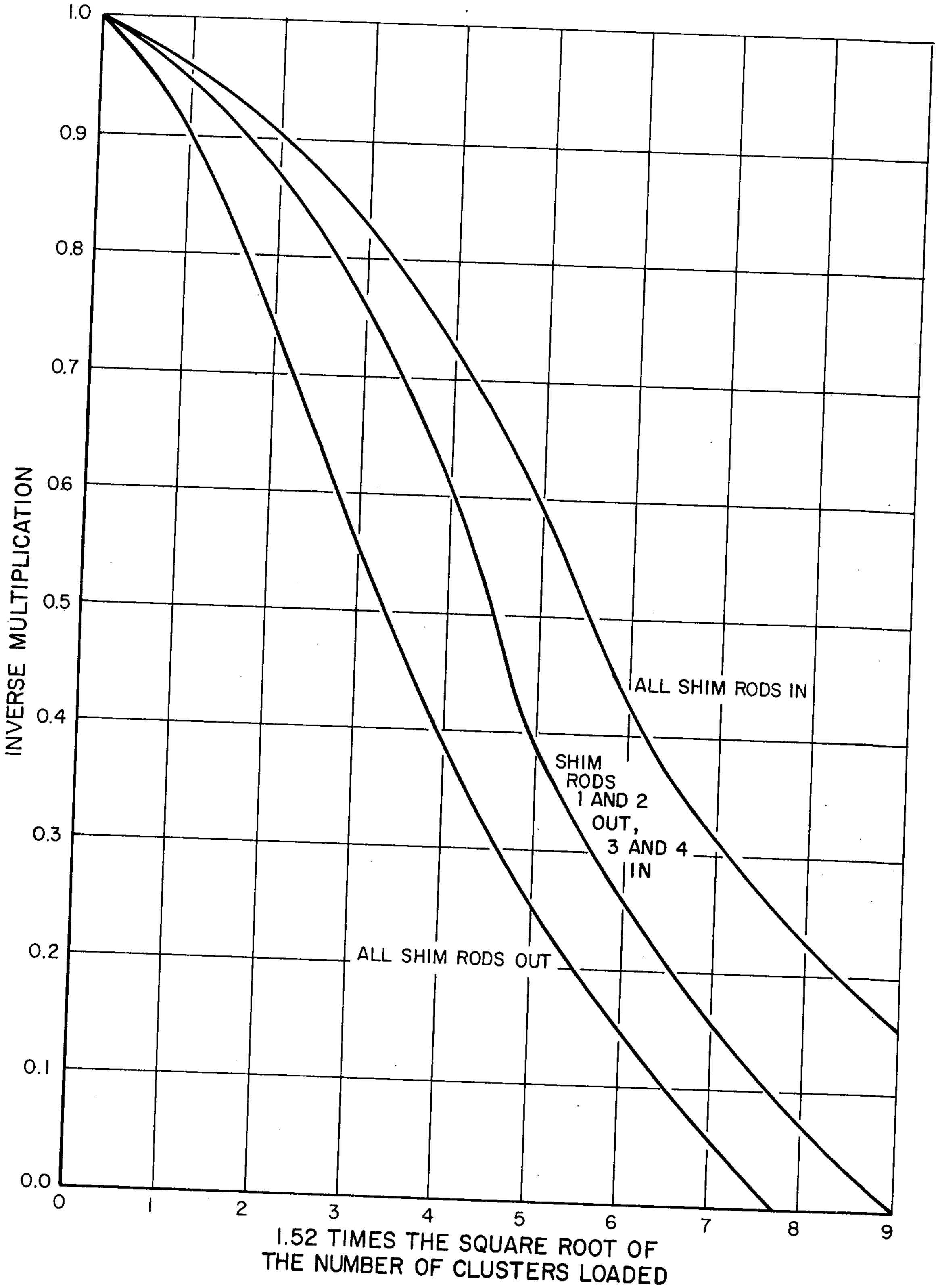
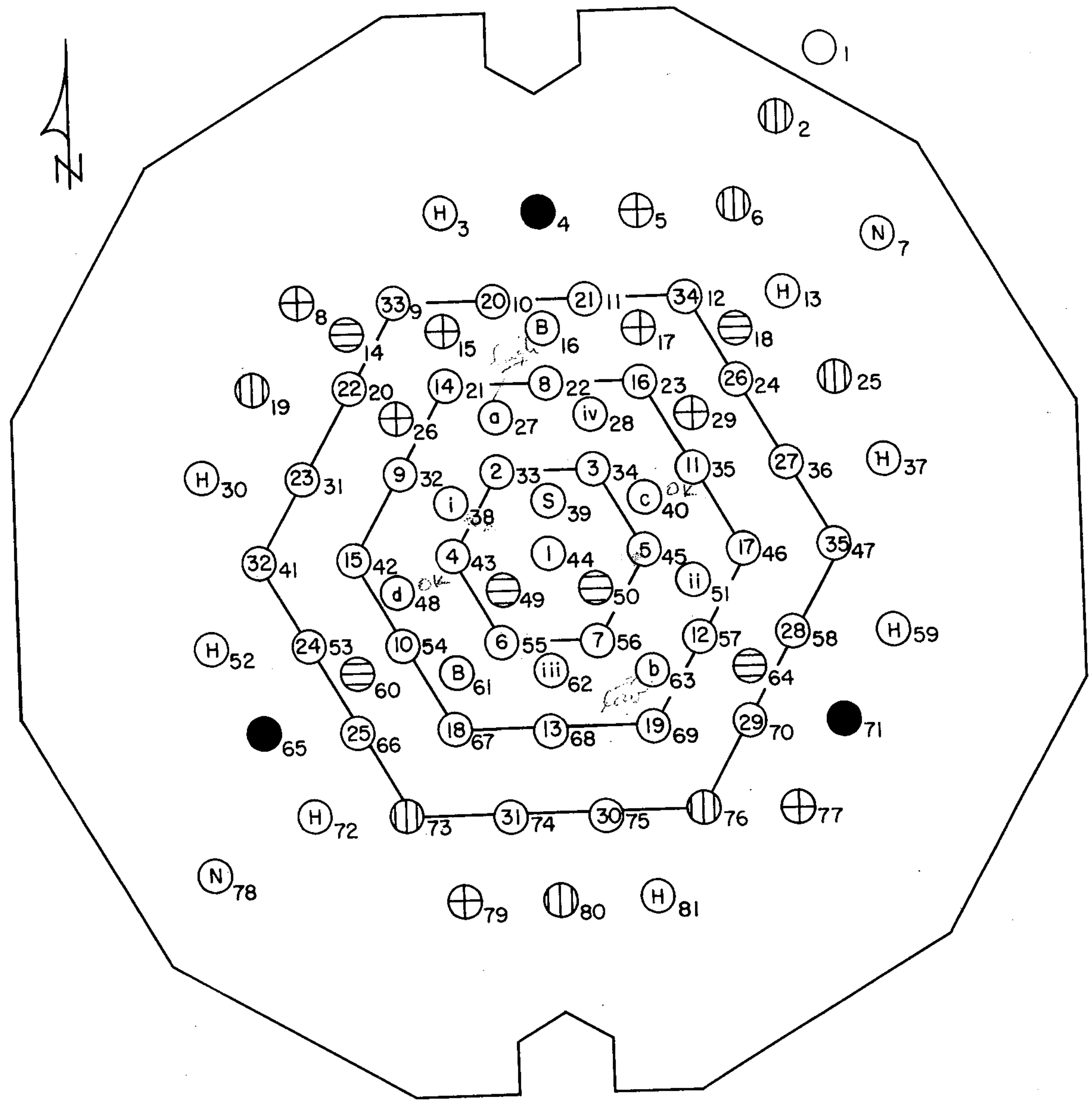


Figure II-5. Criticality Curve Format

See Addendum 1



LEGEND:

- (S) SOURCE
- (●) THIMBLE & FISSION CHAMBER
- (⊕) BLIND PLUG
- (i) SHIM ROD
- (a) SAFETY ROD
- CORNER DUMMY
- CENTER DUMMY
- (1) FUEL AND LOADING ORDER
- (N) Na LEVEL PROBE
- (B) Be TEMPERATURE PROBE
- (H) POOL HEATER
- ( ) SODIUM

Figure II-6. Fuel Loading Sequence

III

PERIOD AND TEMPERATURE INSTRUMENTATION

BY

R. A. LEWIS

ACKNOWLEDGMENT

The author gratefully acknowledges the help given by L. S. Beller of the SGR Critical Facility on the techniques and analysis in this experiment.

CONTENTS

FIGURES

OBJECTIVE

The objectives of this experiment are:

I. To test the effectiveness of the source "removal" technique.

II. To set up the period measurement counting equipment for the low-power tests, to determine the operating parameters (calibration) and resolution time of this equipment, and to test the equipment for unusual statistics.

III. To define the power level range over which period measurements will be made and to determine the required waiting time for period measurements at the SRE.

IV. To set up and calibrate the Sanborn Recorders for use as temperature recorders and to install the thermocouple reference junction.

PURPOSE

This experiment will assure an accurate knowledge of the characteristics of the instrumentation to be used in the low-power tests.

METHOD

The SRE startup neutron source consists of a small cylinder of radioactive antimony inside of a beryllium sleeve. The Sb and the Be portions of the source are separately supported by two coaxial thimbles; i.e. a thimble holding the Sb fits inside the thimble holding the Be sleeve. The inside of the thimble holding the Be, i.e. the outer thimble, is sealed from the reactor environment. The normal procedure for installing the source is to place the outer thimble in the reactor and then install the inner thimble. It is thus possible to move the inner thimble relative to the outer thimble without breaking any seal to the reactor core tank. This fact is the basis of the proposed source "removal" technique. During normal source operation, the Sb cylinder is suspended at the reactor midplane with the surrounding Be sleeve extending 3 feet above and 3 feet below this point.

The procedure for "removing the source will be to hold the outer thimble in place with hold down lugs, install the lift ring and special grapple on the inner thimble, and raise the inner thimble 5 feet with the 5-ton crane. This may be done with all rod drives in place. The effect of the above procedure is to separate the Sb and Be in the neutron source, which should result in a major reduction in the rate of photoneutron emission from the Be sleeve. The actual reduction in subcritical count rate will be measured.

The physical setup of the equipment to be used for period measurements is shown schematically in Figure III-1. Except for the Experimental Unit scaler-timer-printer units, the instrumentation consists of the regular low-level startup channels with a special low-level period amplifier for safety purposes.

A pulse height calibration will be run for each of the two channels shown in Figure III-1. The reactor at steady flux will be used for the neutron source for this test. The reactor drift should not affect the results of the calibration to a significant extent.

The interpretation of period data is complicated by several factors, the most important of which are the problems of waiting time, counting system resolution time, and fuel temperature effects. The time after the introduction of a step increase in reactivity for which the increase in reactor flux has approached to within, for example, 1% of the asymptotic period, is called the "waiting time." The waiting time is a function of the fuel type, the loading of a reactor, and the reactivity prior to the step change. Thus the waiting time is a function of the particular reactor under discussion. Toppel* has calculated theoretical waiting times for various conditions; these calculated waiting times will be checked for the SRE. At the upper (high count rate) ends of period measurements, the counting systems begin to lose a significant fraction of the counts. A knowledge of the system resolution time is required to correct for this loss. Also, because of the negative prompt temperature coefficient of the SRE, a rise of temperature of the fuel tends to depress the rate of power increase at the upper (higher power) ends of period measurements. In this experiment, an attempt will be made to separate these three effects and to evaluate their effect on the accuracy of the reactivity measurements.

---

*B. J. Toppel, Nuclear Science and Engineering, 5, No. 2., 1959.

expanded scale of the

Time response of TC's ?

The approximate power level at which temperature effects in the fuel become important will be determined by monitoring the temperature in a fuel element and also a fuel channel exit temperature during a rise in power on a long period (200 sec). The power level at which the temperature of the fuel has risen one half of a degree will be noted and marked as point "T." The power level at which the channel exit temperature exhibits a noticeable change will be marked and called point "C." Period 1 shown in Figure III-3 will be used for the evaluation of temperature effects.

The next step will be to evaluate the system resolution times. The technique is to place the reactor on a stable period and evaluate the deviation of the count rate rise from a constant period at high count rates. Figure III-2 illustrates this phenomenon. Waiting time effects will be eliminated by applying the Toppel waiting time to the period data obtained. Toppel's waiting time is considered a good preliminary estimate. There is no way to absolutely ensure that temperature effects are not present in the data. However, these effects may be minimized by terminating the period run as far below point "T" as possible. Point "C" in Figure III-3 is an estimate, based on past experience, of the power level at which a fuel-channel exit temperature change is first noted on the control room instrumentation.

Period 2 shown in Figure III-3 will be used for the resolution time determination. The calculation of the system resolution time from this period data is accomplished as follows:

1) Plot the counting data after Toppel's waiting time. This is illustrated in Figure III-2 for a 100-second period. The solid curve in Figure III-2 represents the "measured" data.

2) Fit a straight line by eye through the lower count rate points and extend the line to higher count rates; this represents the "true" count rate as a function of time (dashed curve).

3) Take values of "true" and "measured" count rates at several times (abscissa) in the vicinity of the separation of the curves. Compute τ_a, the apparent resolution time, from the equation:

$$\tau_a = \frac{\dot{n} - \dot{m}}{\dot{n}\dot{m}}, \qquad \ldots (1)$$

where

$\dot{n}$ = "true" count rate

$\dot{m}$ = "measured" count rate.

4) Plot these computed τ_a's as a function of the time as in Figure III-2. This is shown in Figure III-4. The asyptotic value of the apparent resolution time in Figure III-4 is the resolution time, τ, of the system. Using this value of resolution time, the measured count rates may be corrected using the equation*

$$\dot{n} = \frac{\dot{m}}{1 - \dot{m}\tau} \quad \ldots (2)$$

The counting data and resolution time obtained in the test described in the last paragraph may be used in conjunction with an IBM computer code,† Deck No. OW-180, to determine whether or not unusual statistics are being experienced in the counting. The code is discussed in Part E of the Appendix. Qualitatively, the code corrects the counting data for the system resolution time, performs a weighted least-squares fit of the data, and compares the statistics of the measured data with Gaussian statistics. The comparison to normal, i.e. Gaussian, statistics is done on the basis of the relative standard deviation of the measurement. The relative standard deviation is defined as the ratio of the computed standard deviation of the measurement to the standard deviation based on Gaussian statistics.

After eliminating the data points within Toppel's waiting time, the counting data will be submitted for analysis by the code and the results used to perform a Chi-squared test.

The power level limits for period measurements are defined at low power by the sensitivity of the detectors and safety instrumentation considerations, and at high power by the temperature effects discussed above. The power level

*W. J. Price, Nuclear Radiation Detection (New York: McGraw-Hill, 1958), p 48.

†L. S. Beller, "An Accurate Reactivity Measurement Technique for Critical Experiments," presented at the ANS Meeting, Chicago, Summer 1960 (to be published).

represented by point "T" as defined above will be usedas the upper power limit for period measurements. Past experience has shown that 2-1/2 decades of power rise are required for accurate period data. A point "A," defined as the power level 3 decades below point "T," will be used as the power level for the start of period runs. If the point "A" does not fall within the range of the log N channels, it will be marked on the log count rate chart and special low-level safety circuits will be provided for use during period measurements.

The waiting time required for SRE period measurements will be determined for three representative periods between points "A"and "T": a 35-second, a 120-second, and a 300-second period. The waiting time will be evaluated for each of the three periods, starting from the "source out" critical condition and starting from the "source in" subcritical constant flux condition. The calculation of the correct waiting time for each period will make use of the least-squares fit and relative standard deviation computed by the code. The data from each of the six period runs will be submitted several times to the IBM code analysis. Each time, one more of the initial data points will be eliminated; i.e. the first one, then the first and the second, then the first, second, and third, etc. After each analysis by the code, the relative standard deviation will be plotted. As more and more of the initial points are eliminated, the least-squares fit will improve and the relative standard deviation will asymptotically approach a minimum of about one. Here the waiting time will be defined as the number of data points, converted to an equivalent time from the end of the rod withdrawal, that must be eliminated so that the relative standard deviation is within 1% of its minimum value.

The setup and test of the Sanborn Recorders for use as temperature monitors is routine except for the provision of an ice bath for the thermocouple reference junction.

PROCEDURE

I. TEST OF NEUTRON SOURCE REMOVAL TECHNIQUE

This experiment is to begin immediately after the attainment of an operational loading. Nothing will as yet have been removed from the core after the critical test. The reactor will be subcritical with 1000-gpm flow in the main primary, no flow in the auxiliary system, all shim rods fully inserted, and all safety rods withdrawn. The average core temperature will be 340 ± 20°F. The instrumentation for the critical experiment, as shown in Figure III-5, will still be installed and operating.

1. (O, E) Place the regular reactor startup fission chambers at the bottom of their thimbles (Channels I and II, Figure III-5). Connect switches S5 ~~and S6~~ in Figure III-5 so that the log count rate channel and its high flux scram circuit are working through ~~startup Channel I and indicating about 10 counts/sec.~~ Switch S6 should always be connected to Channel I. Change the log count rate channel high flux setpoint so that the reactor will be scrammed if the count rate falls below 1 count/sec.

2. (E) Set the three timers (1, 2, and 3 in Figure III-5) to count for 20 out of 25 seconds. Turn on the printers and record the count rate observed.

3. (E) Using the technique described in Part IV of this procedure, set up four Sanborn channels to monitor a fuel temperature, two fuel-channel exit temperatures, and the reactor outlet temperature.

4. (O) Install hold-down lugs on the outer thimble of the neutron source, R-39. Be careful that these hold-down lugs do not block the inner thimble of the source. Install a lift ring and grapple on the <u>inner thimble</u> of the neutron source in R-39. Attach the 5-ton crane hook in preparation for lifting.

5. (E) In the next step, the Sb and Be in the source will be separated. Since the reactor is already subcritical, the flux intensity will begin to decrease. Follow the flux decay on the log count rate chart and on the special scaler-timer-printer channels. It will be necessary to increase the counting time of the scalers at low count rates in order to follow the decay more accurately. ~~Just before the flux falls low enough so that the log count rate meter shows less than 1 count/sec (off scale),~~ switch S5 so that the log count rate recorder is reading

from the special in-core fission chambers.

6. (O) On request from the Experimental Unit engineer, pull the inner source thimble up 5 feet.

7. (E) Monitor the flux decay until either it levels off or until about 10 counts/second are being recorded on the scalers connected to the special in-core fission chambers.

8. (O) On request from Experimental Unit engineer, reinsert the inner source thimble and disconnect the 5-ton hook and grapple.

9. (E) Monitor the flux buildup. ~~When the flux rises so that the regular startup channels are showing a count rate, switch S5 to startup Channel I.~~ The test is completed when the flux again levels off. Turn off the printers. Insert all shim and safety rods.

10. (E) Turn off all a-c and d-c power to the special critical test instrumentation except the ~~two~~ three SRE scaler-timer-printer units. The ~~two~~ three scaler units are left on to eliminate warmup time later.

11. (O) Remove the special low flux setpoint from the log count rate recorder. Reconnect the source interlock. ~~Make the normal connection between S6 and the log count rate recorder, i.e. eliminate S5 in Figure III-5.~~

12. (E) Remove the chamber protective covers. Disconnect the preamplifier-chamber jumper cables. Decontaminate and remove the cable, preamplifiers, and other special equipment connected with the critical test from the high bay. Disconnect the cables from the scalers in the Sanborn room.

13. (E, O) Remove the three fission chamber assemblies from R-4, R-65, and R-71. Lay them down horizontally on the high-bay floor. Exercise caution to avoid bending the chambers or scraping their extremities on the floor. Have Health Physics monitor this operation. Take smears and decontaminate if necessary.

14. (O) Replace the thimbles in ~~R-4,~~ R-65, and R-71 with center channel dummy elements.

15. (E) Disassemble the chamber assemblies. Pack the fission chambers in their shipping tubes. Store the chambers and the stiffener assemblies in the Butler building.

16. (O) Disconnect Switch S4 in Figure III-5 and remove the special low-level period amplifier rack used in the critical test from the control room.

II. SETUP AND TEST OF PERIOD COUNTING EQUIPMENT

A. Physical Setup

The physical setup is shown schematically in Figure III-1. As shown, both regular reactor startup channels will be monitored to ensure that all necessary period data will be recorded. The signal cables from the PHS outputs will enter the Sanborn room in the northeast corner. Operations will provide the two WL6376 fission chambers, the two preamplifiers, the connecting signal and power cables to the amplifiers, and signal leads from the PHS outputs of the amplifiers to the Sanborn room. It will be the responsibility of the SRE Systems Unit to see that this equipment is in good working order.

17. (E) Check to see that the correct connections have been made at the PHS outputs of the Operations amplifiers.

18. (E) Connect the signal cables to the two SRE scaler units shown in Figure III-1.

B. Pulse Inspection and Calibration

19. (E) Obtain graphs of alpha count rates vs PHS (Pulse Height Selector) from R. J. Hall for each of the fission chambers for the 0.5 Mc amplifier band width. Convert these data to alpha counts/5 seconds. Prepare a semilog plot of alpha counts/5 sec vs PHS for each channel.

20. (E) Set the timers for 5-sec counting times and 3-sec print-out times.

21. (E, O) Place the Log N compensated ionization chamber at the bottom of its thimble. Place the two startup fission chambers at full insertion. As the reactor flux is increased in the next step, record where the log count rate and log N channels overlap. Compare this with Figure III-3.

22. (O) Bring the reactor up to a flux level one decade off the bottom of the log N chart. Any convenient shim rod configuration is permissible. Hold the flux level at this point as constant as possible, controlling from the log N or electrometer recorder.

23. (E) Ask Operations to check to see that the high voltage on the fission chambers is 300 ± 10 volts.

24. (E, O) Set the Operations pulse amplifiers for both fission chamber channels at FINE GAIN, 3/4; COARSE GAIN, 64; and BANDWIDTH, 0.5 Mc. In case of power loss at any time during these tests, allow a 1-hour warmup period per minute of power loss up to the full 2-hour warmup period.

25. (O) Adjust the positions of the fission chambers to obtain roughly 1000 counts/sec at the scalers.

26. (E) Attach a model 535 Tektronix Oscilloscope, or the equivalent, to the HIGH OUTPUT jack of each of the two pulse amplifiers in turn. The pulse shapes which should be seen are shown in Figure III-6. Photograph, or record in a notebook, the actual pulse shapes (voltage vs time) observed.

27. (E) Run a neutron calibration for the Systron channel as follows: Working as quickly as possible, take three 5-sec counts at 2 volt PHS intervals from 10 to 36 volts. Average each set of 3 counts and plot on the graph of alpha counts vs PHS prepared for this channel in Step 19. If the noise level is low enough, a curve like Figure III-7 will result. In this case, choose the PHS setting for which the neutron-to-alpha count ratio is 1000-to-1 and set it on the Systron channel amplifier. If a typical calibration curve does not result, call R. W. Woodruff.

28. (E) Repeat Step 27 for the Beckman channel.

C. Fuel Temperature Effect Test

29. (O) Adjust flux level to one-half decade from the bottom of the log N chart. Re-adjust the shim configuration so that shim rod 3 is at 5000 V. U.

30. (O) Position the fission chambers so that 10 to 50 counts per second are indicated on each channel. Hold the flux constant at this level for 20 minutes. Do not move the fission chambers again until instructed to do so.

31. (E) Set the Beckman system to count for 10 out of 13 seconds and the Systron system to count for 10 out of 11 seconds. Start the Sanborn Recorders.

32. (E) In the next step the reactor will be placed on a 200-second period. Assign one man to watch the log N chart, one man to watch the Fuel Channel Na Exit Temperature (continuous) Recorder, and one man to watch the Sanborn Recorder monitoring the fuel temperature. As the power rises, the man watching the fuel temperature will announce when the temperature has risen 1/2°F; at this instant, the man watching the Log N chart will mark the power level as point "T." As the power continues to rise, the man watching the Fuel Channel Na Exit Temperature will announce when a noticeable step increase appears on the recorder; the power level at this instant will be marked as point "C." The power will then be reduced.

33. (O, E) Pull shim rod 3 to place the reactor on an approximately 200-second period as indicated by the period recorder. When the rod withdrawal stops, start the scalers and mark the Sanborn charts. No rod motion should occur after the printers are turned on. This period is shown as Period 1 in Figure III-3.

34. (E, O) As the power rises, mark points "T" and "C." When point "C" is reached, immediately insert shim rod 3 and reduce the power to 1/2 decade from the bottom of the log N chart. Turn off the scalers and Sanborn Recorders.

D. Determination of System Resolution Times

35. (O) At this point, the reactor should be at constant flux, at a power of 1/2 decade up on the log N chart. Adjust the positions of the shim rods such that constant flux is maintained and shim rod 3 is at 5000 V.U.

36. (O) Place the fission chambers all the way into their thimbles.

37. (E) Recheck to see that the source interlock and low-level period amplifiers are connected as shown in Figure III-1. These interlocks may not be bypassed at low flux levels with the source withdrawn.

38. (O) Withdraw the reactor startup source according to Steps 4 and 6 under the direction of the Chief Operator. As the source is withdrawn, hold the

flux constant by adjusting shim rod 3. Approximately 1/2 in. of shim rod 3 withdrawal is expected to be necessary.

39. (O) Reduce reactor flux level to 10 counts/sec on the log count rate channel and steady the power at this level.

40. (E) Set the Beckman system to count for 5 out of 7 seconds and the Systron printer to count for 5 out of 6 seconds. Start the Sanborn Recorders.

41. (O, E) Readjust the shim rod configuration so that shim rod 3 is at 5000 V.U. Hold the power level set in Step 39 (10c/s on the log count rate channel) as steady as possible for 20 minutes. Draw a straight line on the log count rate chart indicating a 130-second period. This is done by drawing a line which rises two decades in ten minutes. Pull shim rod 3 to obtain a period such that the log count rate recorder pen is moving parallel to the line drawn on the chart. When the rod withdrawal stops, turn on the printers and mark the Sanborn charts. Do not move any shim rods after the printers are started.

42. (E, O) Allow the reactor flux level to rise continuously throughout the range of the log count rate channel and onto the log N channel. When the power level has risen three decades on the log N or has reached point "C," whichever is the lower power, turn off the printers and insert shim rod 3 to reduce the reactor power to one-half decade up on the log N. Turn off the Sanborn Recorders. In the above period run, the regular period chart will be in operation only during the last part of the power rise, i.e., that part registered on the log N chart. The period should have been 130 ± 30 seconds. If the period was outside of these limits, use the above measured period as an approximate rod calibration and estimate the amount of rod necessary to obtain the desired period. Then re-run the test in Steps 39, 40, 41, and 42.

43. (E) Using the data obtained in Step 42, compute the system resolution times for the Beckman and Systron counting channels, using the method described in Steps 44 through 49. Use Toppel's waiting time for $k_{eff} = 1$. While the analysis in Steps 44 through 52 is in progress, proceed with Step 53.

44. (E) Plot the entire counting data from each period measurement on semilog paper. Plot the counts at the beginning of the counting intervals. Plots analogous to Figure III-2 should be obtained. Mark off Toppel's waiting time on the graphs.

45. (E) The data points above the waiting time cut-off should fall very nearly on a straight line and deviate from it at count rates of about 10^4 counts per second, as illustrated in Figure III-2. In the manner of Figure III-2, estimate the best straight line through the data points above the waiting time cut-off and below a count rate of about 5×10^3 counts/sec; draw in this straight line and extend it as shown by the dashed line in Figure III-2. Calculate the analytical expression for this straight line.

46. (E) Note roughly where the data curve deviates from the straight line. Starting with measured data points well before the apparent deviation of the curves, use the analytical expression derived in the last step to compute "true" (constant period) data points corresponding to each "measured" data point. Do this for each measured data point, including the last one recorded.

47. (E) Calculate the "apparent" resolution time for each pair of data points, true and measured, found in the last step, using the equation

$$\tau_a = \frac{n - m}{nm} \Delta t, \qquad \ldots (3)$$

where

n = extrapolated true count,

m = measured count,

Δt = constant counting interval in seconds.

Calculate the standard deviation of each apparent resolution time from the equation

$$\sigma_{\tau_a} = \tau_a \left\{ (n + m) \left[\frac{1}{(n - m)^2} + \frac{1}{nm} \right] \right\}^{1/2} . \qquad \ldots (4)$$

48. (E) Plot the computed τ_a values as a function of time after the beginning of the period run as shown in Figure III-4. Flag each value according to Equation 4. The calculated apparent resolution times should approach an asymptote in the vicinity at which the count rates are 1×10^4 to 5×10^4 counts/sec. Record this asymptotic value. It is the resolution time of the system.

49. (E) Perform Steps 44 through 48 for each of the two counting channels.

E. Analysis for Unusual Statistics

50. (E) Two sets of period data and an estimate of the system resolution time for the scaler on which each set was taken are now available from Steps 25 through 49. Eliminate the data points from each set according to Toppel's waiting time. Submit each set of data for analysis by the IBM code described in Part E of the Appendix.

51. (E) The code will print out the relative standard deviation of each set of counting data (called Q/(n-2) in the code). If this value is less than 3, normal statistics exist; if less than 5, there is some permissible noise; if above 5, there is something wrong. In the latter case, suspend operation and analyze the circuitry to find where the noise is being picked up.

52. (E) The computer analysis in Step 50 will also provide the constants of a straight-line least-squares fit of the data. Use this equation and repeat the estimate of the system resolution times by means of Steps 46 through 49.

III. PERIOD RUN POWER LIMITS

A. Specification of Upper Power Limit

53. Point "T" as defined in Step 32 will be used as the upper power limit for period runs.

54. (E) If "T" is three or more decades above the bottom of the log N chart, perform Step 55. If "T" is less than three decades above the bottom of the log N, perform Step 56 and omit Step 55.

B. Specification of Lower Power Limit

55. (E, O) If "T" is more than three decades above the bottom of the log N chart, set the point "A," at which all period measurement will begin, by the following procedure:

a) Adjust the reactor power level to one decade below point "T" on the log N chart. Mark this power level as point "B."

b) Position the fission chambers so that each channel is reading 1,000 counts per second.

c) Reduce reactor power by 2 decades on the log count rate channel, i.e. to 10 counts/sec. Mark this power level as point "A" on the log N recorder.

The fission chambers are now positioned for all low-power period measurements. Record their positions. Do not move the fission chambers after this step except in the case of a shutdown. Then return the chambers to these positions.

Proceed to Step 57 and omit Step 56.

56. (E, O) If "T" is less than 3 decades above the bottom of the log N chart, set the point "A," at which all period measurements will begin, by the following procedure:

a) Adjust the reactor power level to 1 decade below point "T" on the log N chart. Mark this power level as point "B."

b) Position the fission chambers so that each channel is reading 1,000 counts per second.

c) Mark the point 1 decade from the bottom of the log count rate recorder as point "A" on the log count rate chart, i.e. 10 counts/sec.

The fission chambers are now positioned for all low-power period measurements. Record their positions. Do not move the fission chambers after this step except in the case of a shutdown. Then return the chambers to these positions.

C. Determination of the Waiting Time

57. (O) Adjust the reactor power level to point "A." Adjust the shim rod configuration to place shim rod 3 at 5000 V.U. Hold the flux constant for 20 minutes.

58. (E) Set the Beckman System to count for 10 out of 13 seconds and the Systron system to count for 10 out of 10.5 seconds.

59. (E, O) Pull shim rod 3 for a 120 ± 20 second period as indicated on the period recorder. All rod motion must stop before the flux has risen one-half decade above point "A." If the period is not yet correctly established by the time

the flux reaches one-half decade above point "A," return to point "A" and repeat Steps 57 through 59. When the rod withdrawal stops, turn on the printers. Do not move any shim rods after the printers are turned on.

60. (O, E) When the power level reaches point "T," insert shim rod 3 and reduce the power to point "A." Turn off the printers. Hold the power constant for 20 minutes.

61. (E) Set the Beckman system to count for 5 out of 8 seconds and the Systron System to count for 5 out of 5.5 seconds.

62. (O, E) Repeat Steps 59 and 60 for a 35 ± 5 second period.

63. (E) Set the Beckman System to count for 20 out of 23 seconds and the Systron System to count for 20 out of 20.5 seconds.

64. (O, E) Repeat Steps 59 and 60 for a 300 ± 50 second period.

65. (O) Reinsert the neutron source under the direction of the Chief Operator. Hold the flux constant by adjusting shim rod 3.

66. (O, E) Repeat Steps 58, 59, and 60.

67. (O, E) Repeat Steps 61 and 62.

68. (O, E) Repeat Steps 63 and 64.

69. (O) Insert all shim and safety rods.

70. (E) Submit each of the 12 sets of counting data obtained in Steps 59 through 68 to the following analysis: Run each set of data through the least-squares fit by the code, the first time with all data points, then without the first data point, then without the first and second data points, etc. Each time, the code will compute a relative standard deviation $\left(Q/(n-2)\right)$ for the set of counting data. The first few calculations, including data points before the asymptotic period is established, will have large relative standard deviations. But as more and more of the initial points are eliminated, the relative standard deviation will asymptotically approach a minimum of 1 to 3. For each of the twelve period measurements, estimate the number of data points which must be eliminated in order to approach within 1% of the minimum standard deviation for the set of data; i.e., if the minimum approached

is 2.25, then 2.27 is within 1%. Convert the number of data points eliminated for each case into an equivalent waiting time from the beginning of the run. Plot these results as waiting time vs period.

IV. TEMPERATURE MEASURING EQUIPMENT

A. Physical Setup

71. (E) All thermocouple leads will be brought into the "Sanborn Panel" on the north wall of the Sanborn room.

72. (E) Place the thermocouple reference junction ice bath in front of the Sanborn Panel on the floor.

73. (E) Place the Sanborn Recorders and low-level preamplifiers along the northeast wall of the Sanborn room.

74. (E) For each thermocouple to be used, attach extension wires of thermocouple material to the Sanborn panel plugs. Be sure that the extension leads are matched to the thermocouple material at the Sanborn panel plug. Run these extension wires to the ice bath. Connect copper wires to both thermocouples leads at the ice bath and run these leads to the input plug on the low-level Sanborn amplifiers.

75. (E) Twelve channels are available for simultaneous recording of thermocouples or any analog variable in the range 0 to 100 mv.

B. Calibration of the Sanborn Recorders for Use with Thermocouples*

76. (E) Measure the input (source) impedance of the thermocouple to be monitored between the leads at the point they are to be connected to the low-level amplifiers.

77. (E) Set a small rheostat to this source impedance and connect the rheostat across the input leads to the low-level amplifier to simulate the thermocouple with zero signal. Turn on the preamplifier and allow a 30-minute warmup period.

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*Sanborn Low Level Preamplifier Instruction Manual, Sanborn Co., Waltham, Mass.

78. (E) Set the zero suppression switch to "OUT". Set the ATTENUATOR to "OFF" and adjust the position control to place the pen at midscale.

79. (E) Reset ATTENUATOR to X1 and press CAL button intermittently. Adjust the sensitivity control for two centimeters of stylus deflection as the button is pressed. Return ATTENUATOR to "OFF".

80. (E) The chart is now calibrated in terms of the equivalent open circuit voltage of the thermocouple with a sensitivity of 100 microvolts/cm at X1, 500 microvolts/cm at X5, etc.

81. (E) Standardize as follows: Set ATTENUATOR to "OFF" and the ZERO SUPPRESSION switch to "IN". Remove connector from INPUT socket. Set SUPPRESSION RANGE switch to "STD" and turn ZERO SUPPRESSION control to zero. Set the stylus to midscale with the position control. Set ATTENUATOR to "STD" and return stylus to midscale with the STANDARD control.

82. (E) Connect the thermocouple leads to the INPUT connector.

83. (E) For use as a suppressed zero instrument reading the thermocouple voltage, set the ATTENUATOR to "OFF" and set the stylus to midscale with the position control. Set the ZERO SUPPRESSION control to "IN". Advance the ZERO SUPPRESSION control and the ATTENUATOR together until the ATTENUATOR is at X10 (suppression range = ± 10) and the stylus is back to midscale again. The instrument is now balanced. The open circuit voltage of the thermocouple may be read directly from the ZERO SUPPRESSION CONTROL dial at the sensitivity given in the following table:

Suppression Range (mv)	Zero Suppression Control Voltage Sensitivity (volts/dial division)
+ 100	+ 100
+ 10	+ 10
- 10	- 10
- 100	- 100

The voltage thus read may be converted into temperature by referring to a calibration table for the particular thermocouple with 0°C reference junction temperature. Any drift in the monitored temperature will show up as a stylus deflection which can then be converted to voltage, and thus temperature, according to the calibration in Steps 77, 78, and 79.

APPENDIX

A. SCHEDULE

The starting date will be at the conclusion of critical test. Part I, the source removal test, will require about 2 hours, Part II about one day, Part III about one day, and Part IV will be done concurrently with Parts II and III. Thus, a total of three days of reactor time is required.

B. MANPOWER REQUIREMENTS

The regular operating crew plus one engineer and technician from the Experimental Unit will be required on each shift.

C. EQUIPMENT REQUIREMENTS

Access to the regular startup channel equipment as shown in Figure III-1.

4 Sanborn Recorder Channels.

2 scaler-timer-printer units in separate racks.

1 fuel thermocouple, 2 fuel channel exit thermocouples, and 1 reactor exit thermocouple.

Tektronix Model 535 Oscilloscope, or the equivalent.

Special instrumentation used for the critical experiment, as shown in Figure III-5.

D. CREDIBLE ACCIDENTS

A short period is possible during the period measurements. However, no period or flux scram interlocks will be bypassed and special low-level period scram circuits will be provided during the low-power runs. The low-level period circuit will provide a scram at 4 seconds.

E. DESCRIPTION OF CODE FOR THE REDUCTION OF PERIOD DATA*

The following input information is required by the code: A run number, the number of data points submitted for analysis, the cycle time of the scaler-timer-printer, the actual counting time (cycle time minus print-out time), the system resolution time, and each raw data point. The code does not automatically correct for the waiting time. The data points from the period run which fall within the waiting time must be eliminated before submitting the data to the code for analysis; i.e., only data points after the waiting time are entered to the code.

The code first corrects each data point for the system resolution time. The data points should then follow the exponential equation

$$y(t) = A_o e^{\omega t}, \qquad \ldots (5)$$

which may be written as

$$z = a + bt, \qquad \ldots (6)$$

where

$z = \ln y(t)$,
$a = \ln A_o$,
$b = \omega = 1/T$.

The code next performs a weighted least-squares fit of the data in the straight line form of Equation 6. The result gives the constants, a_o and b_o, of the equation

$$Z = a_o + b_o t. \qquad \ldots (7)$$

The least-squares fit is made on the assumption that the data points are distributed in a Gaussian distribution about a straight line of the form of Equation 6.

*L. S. Beller, "An Accurate Reactivity Measurement Technique for Critical Experiments," presented at the ANS Meeting, Chicago, Summer 1960 (to be published).

If this assumption is correct, then the probability of the appearance of a point z_i in the counting data is:

$$\text{Prob. of } z_i = \frac{1}{\sigma_i \sqrt{2\pi}} \exp\left[- \frac{(Z_i - z_i)^2}{2\,\sigma_i^2} \right], \qquad \ldots (8)$$

where Z_i is calculated from the fitted line, Equation 7, for the same time as the measured point z_i. The quantity σ_i is the standard deviation of the data points around Equation 7. On the basis of Equation 8, the probability of getting the particular set of n data points under analysis is the product of the individual probabilities of the form of Equation 8; that is,

$$\text{Prob. of measured array} \simeq \left(\frac{1}{\sigma_i \sqrt{2\pi}} \right)^n \exp\left[- \frac{\sum_{i=1}^{n} (Z_i - z_i)^2}{2\,\sigma_i^2} \right], \qquad \ldots (9)$$

or

$$\text{Prob. of array} \simeq \left(\frac{1}{\sigma_i \sqrt{2\pi}} \right)^n \exp\left\{ - \frac{\sum_{i=1}^{n} [(a_o + b_o t_i) - z_i]^2}{2\,\sigma_i^2} \right\}. \qquad \ldots (10)$$

The problem now arises as to how to estimate σ_i, the standard deviation of the measurement. The approximation which is used, based on the assumption of Gaussian statistics and a large number of data points (say, $n > 20$), is to replace σ_i by η_i, its best experimental estimate. η_i is found as follows:

$$z(t) = \ln\ y(t),$$

$$dz = \frac{1}{y}\ dy,$$

or

$$\eta_i \simeq \frac{1}{y}\, \sigma_{y_i}, \qquad \ldots (11)$$

where σ_{y_i} represents the standard deviation of the actual count. But under the assumptions listed above, we have

$$\sigma_y = \sqrt{y} \qquad \ldots(12)$$

from which

$$\eta_i = \frac{\sqrt{y_i}}{y_i}, \qquad \ldots(13)$$

or

$$\eta_i^2 = \frac{1}{y_i}. \qquad \ldots(14)$$

Substituting η_i^2 from Equation 14 for σ_i^2 in Equation 10 gives

$$\text{Prob. of array} \simeq \left(\frac{1}{\eta_i \sqrt{2\pi}}\right)^n \exp\left\{-\frac{1}{2}\sum_{i=1}^{n}\left[(a_o + b_o t_i) - z_i\right]^2 y_i\right\} \ldots(15)$$

By the definition of the best straight-line fit as that line giving the most probable Gaussian array of points, the constants a_o and b_o in Equation 15 are chosen so as to minimize the sum in the brackets in Equation 15; i.e., a_o and b_o are chosen to give the least sum of the squares of the weighted (by y_i) residuals.

Once the best-fit line is established, the code calculates the square of the weighted residual of each data point; i.e.,

$$r_i^2 = \frac{(Z_i - z_i)^2}{\eta_i^2}. \qquad \ldots(16)$$

Since η_i is the estimate of the standard deviation of the measurement, r_i is the ratio of the individual residual to the estimate of the root-mean-square residual. Thus, r_i for each data point should be in the vicinity of 1 to 3.

The sum of all the individual r_i^2 is equal to Chi squared:

$$\text{Chi squared} = Q = \sum_{i=1}^{n} r_i^2. \qquad \ldots(17)$$

This sum is calculated by the code and may be used to make a Chi-squared test of the measurement. The probability of getting a particular Chi-squared value for n-2 degrees of freedom may be found in statistical tables.

The code also computes the relative standard deviation of the measurement; i.e.,

$$\left(\frac{\sigma_{\text{measured}}}{\sigma_{\text{Gaussian}}}\right)^2 = \frac{Q}{n-2} = \frac{\sum_{i=1}^{n} r_i^2}{(n-2)}, \qquad \ldots(18)$$

where σ_{measured} represents the standard deviation of the measurement. For good statistics (i.e. near Gaussian), Q/(n-2) should be about unity.

Finally, the code computes and prints out:

1) The run number.
2) The period, $T = \frac{1}{\omega}$, in seconds.
3) The standard deviation of the period.
4) The fractional standard error in the period.
5) The reactivity in cents as calculated from the in-hour equation, using the Keepin and Wimmet fast-fission data.*

---

*Nucleonics, <u>16</u> No. 10, 1958.

6) The plus or minus reactivity range based on the standard error in the period.

7) The constants a_o and b_o of the fitted straight line.

8) $Q = \sum_{i=1}^{n} r_i^2$ = Chi squared.

9) $Q/(n-2)$, the relative squared standard deviation of the measurement.

10) The individual relative residuals, r_i, printed in the same order as the input data was entered.

The code takes about 10 seconds per problem.

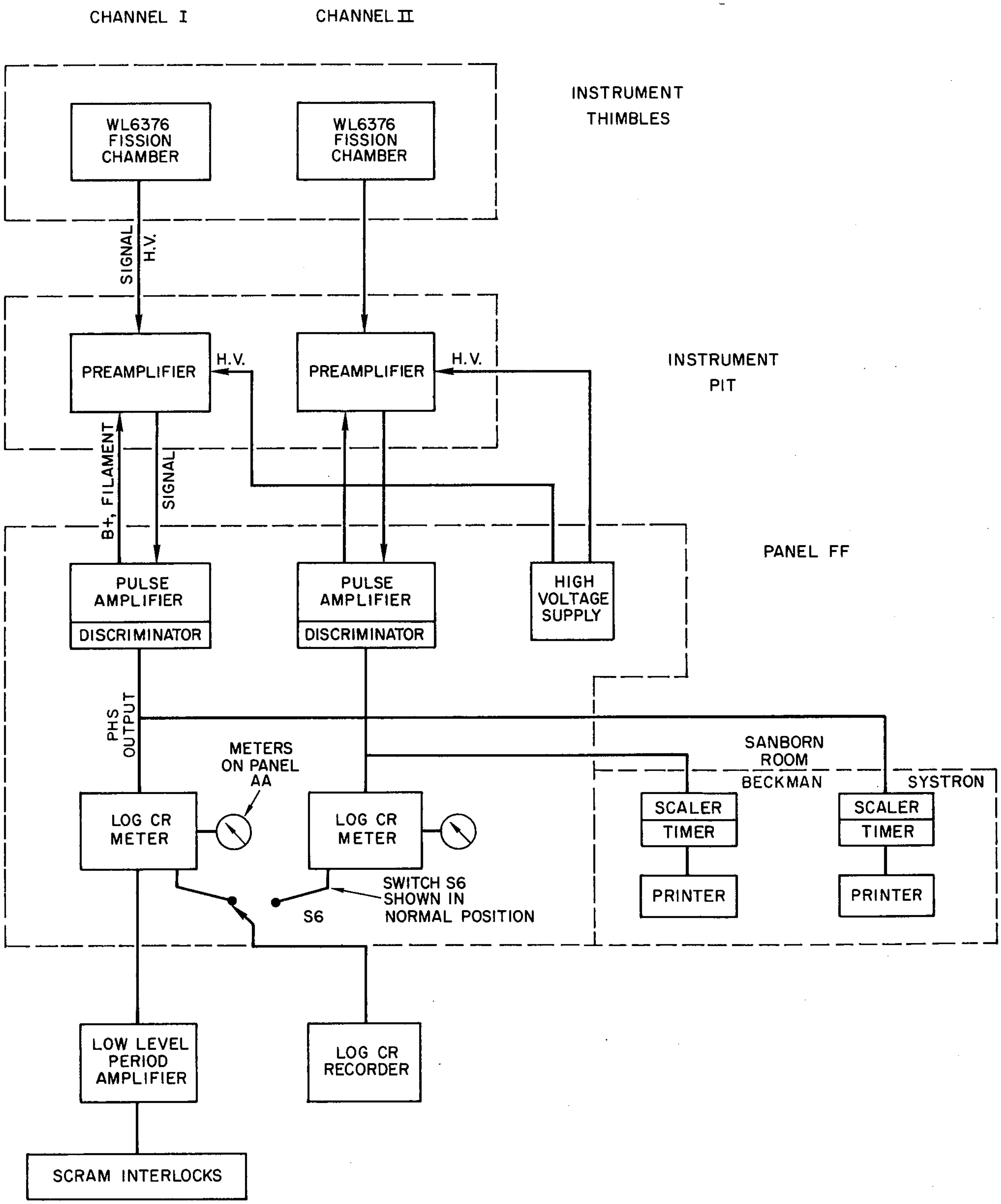


Figure III-1. Equipment for Period Measurements

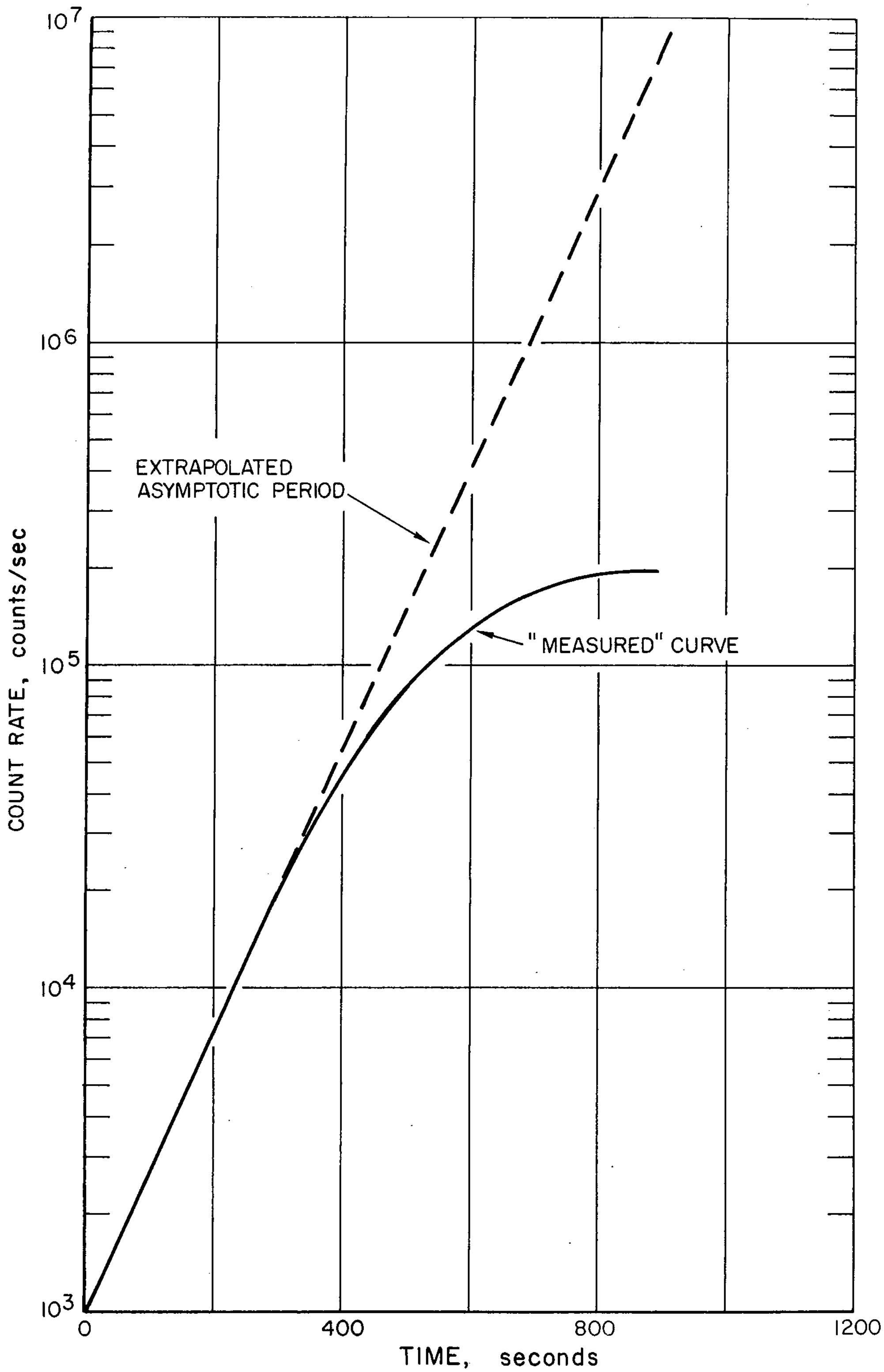


Figure III-2. Typical Period Data Curve

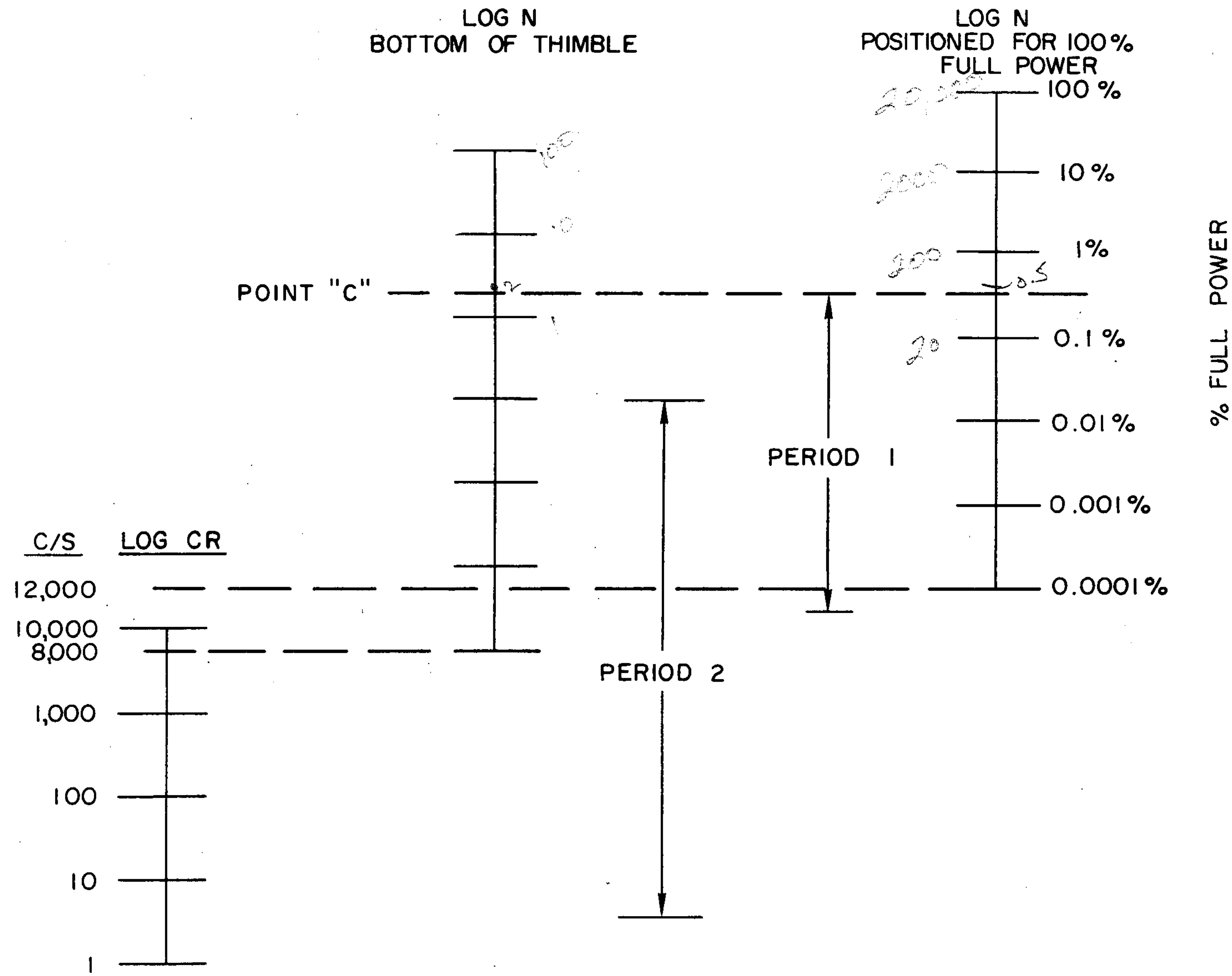


Figure III-3. Log Count Rate and Log N Channel Coverage

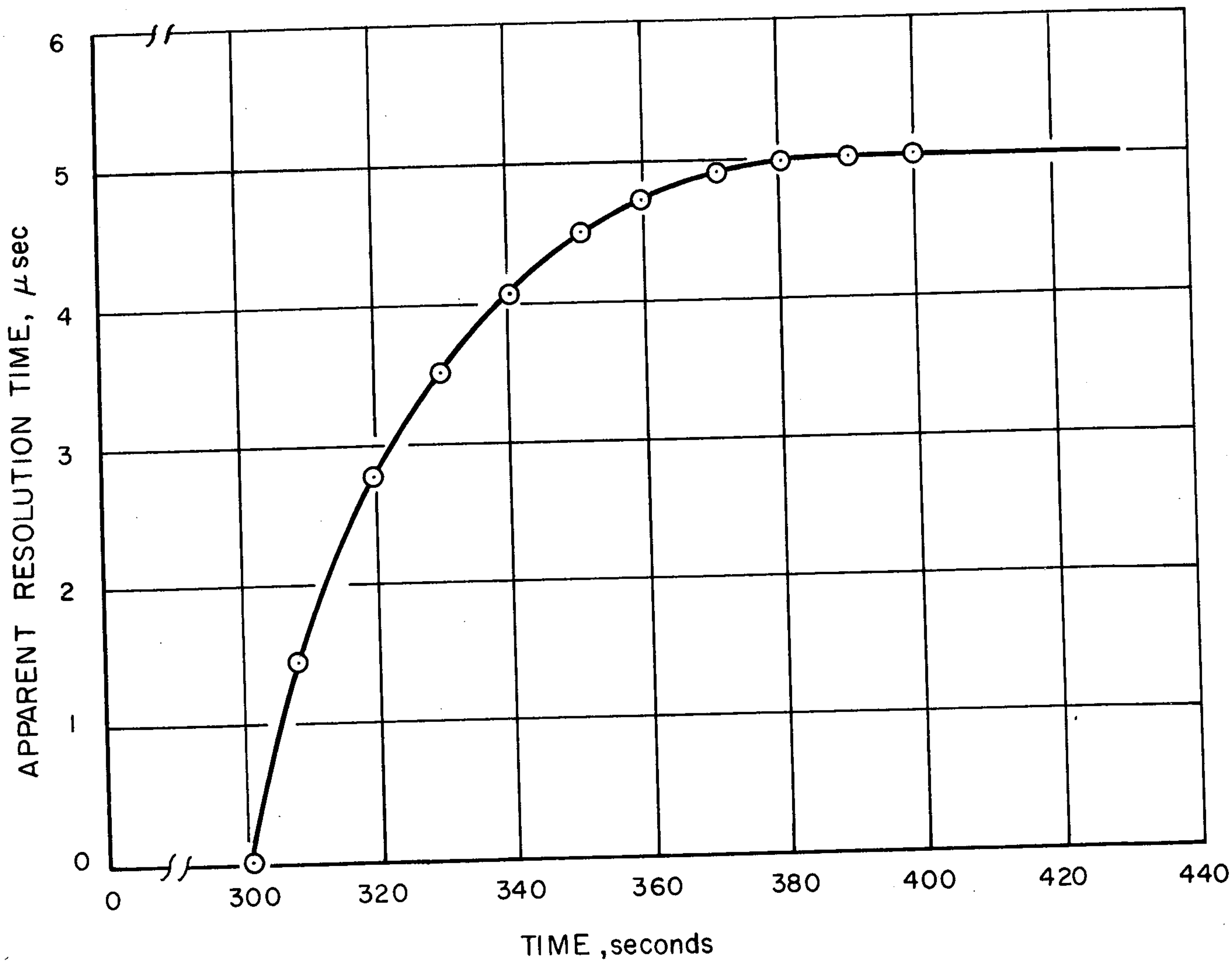


Figure III-4. Typical Apparent Resolution Time Calculation

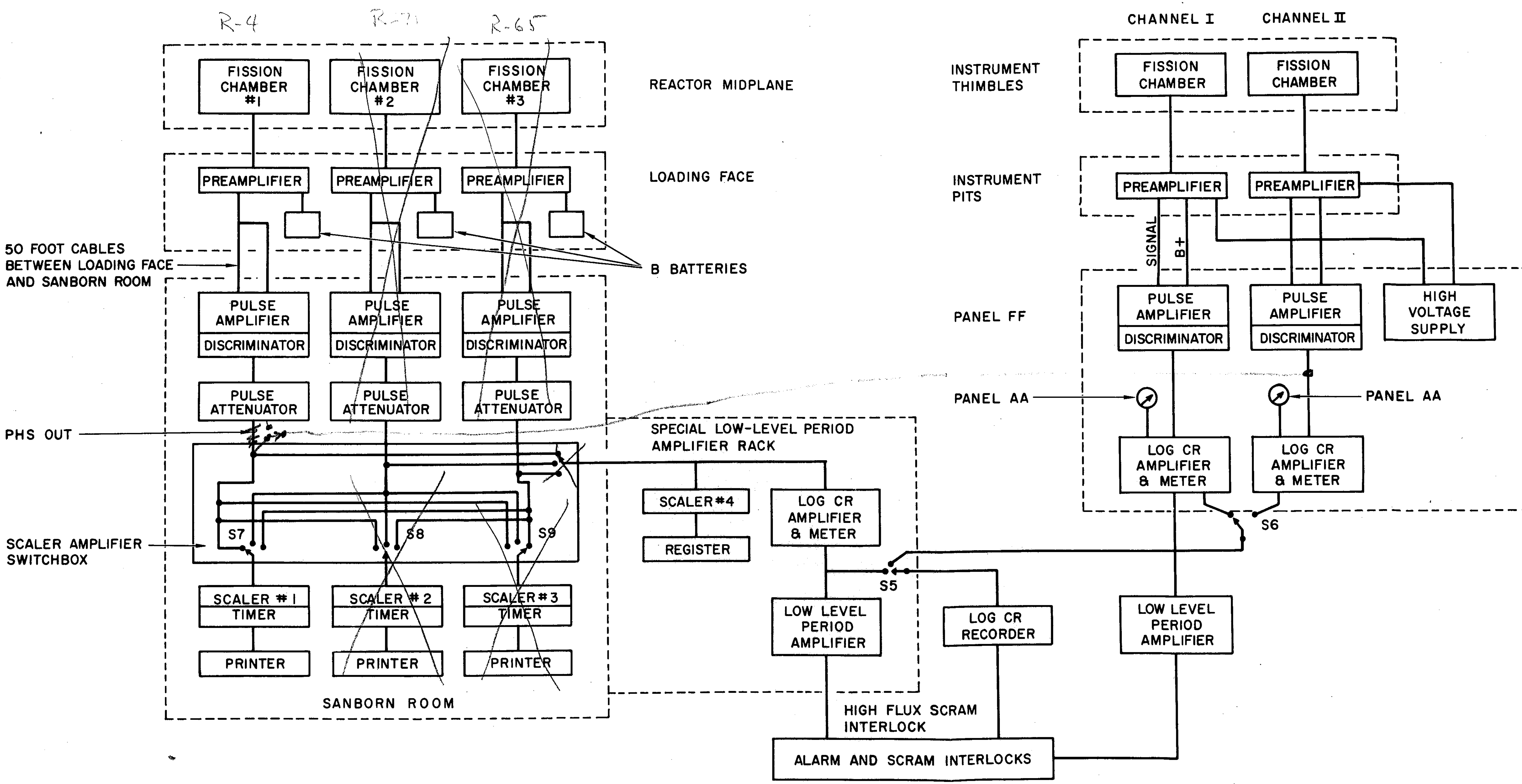


Figure III-5. Instrumentation for Critical Test

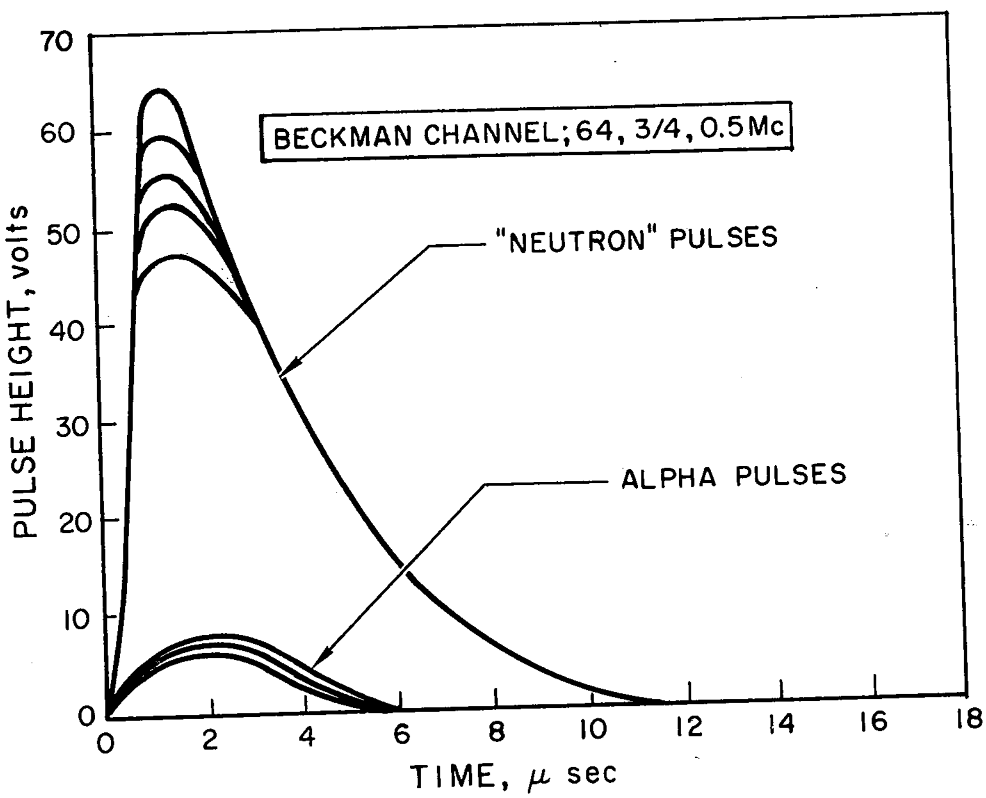


Figure III-6. Typical Pulse Shapes

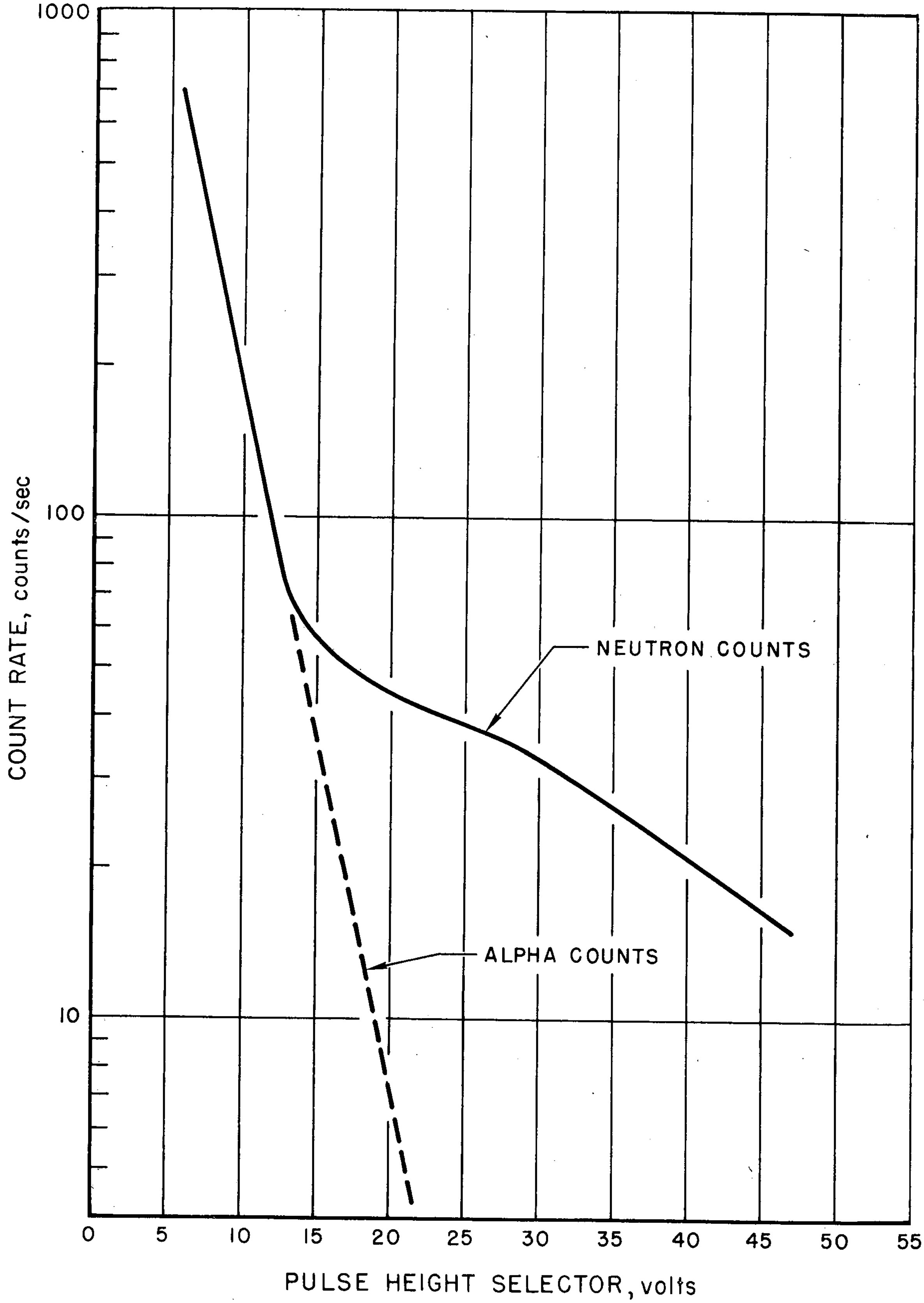


Figure III-7. Typical Pulse Height Calibration

IV

SHIM AND SAFETY ROD CALIBRATIONS

By
R. W. KEATEN

Page

OBJECTIVE

In this experiment, the shim and safety rods will be calibrated with the operational loading of thorium-uranium fuel clusters.

PURPOSE

The shim rod calibrations are needed for later experiments, i.e., measurements of the statistical weight, zero power transfer function, and isothermal temperature coefficient, and also for the studies of reactivity histories to determine core normalcy. To investigate the effect of shadowing, two different calibrations will be made with shim rod 3: one against shim rod 4 and one against the other three shim rods in a gang. The safety rod calibrations are necessary for the safe operation of the reactor.

METHOD

Two differential calibrations of shim rod 3 will be made. In the first, shim rod 3 will be calibrated against shim rod 4, with shim rod 1 out and shim rod 2 in. In the second, shim rod 3 will be calibrated against the other three shim rods, which will be ganged. The approximate shim rod positions at the beginning and the end of each of these cases are shown in Figure IV-1. In both cases, shim rod 3 will be calibrated at 6-inch intervals over the entire length of the rod. At each position of shim rod 3, three periods will be measured: approximately 200 seconds, 100 seconds, and 30 seconds. The periods will be converted to reactivity by means of the in-hour equation. The differential worth of shim rod 3 is then the difference in reactivity between two periods divided by the difference in position. Integral worth curves will be obtained by integrating over the differential worth curves.

Shim rods 1, 2, and 4 will be calibrated by comparing them to shim rod 3 at 6-inch intervals. The integral worth of each of the safety rods will be obtained by measuring the change in the position of shim rod 3 necessary to balance the complete insertion of the safety rod.

PROCEDURE

Steps 1 through 14 will be used to calibrate shim rod 3 against shim rod 4. If the neutron source can be removed, the alternate procedure will be applied.

1. (O) Heat the core to 340°F with the process line heaters, and, if necessary, with the pool heaters, and maintain it in an isothermal condition. The main primary inlet and outlet sodium temperatures should not drift more than 1° per hour; the average temperature should always remain within 5° of 340°F. Set and maintain the main primary flow at 1000 gpm. Shut down the auxiliary primary system.

2. (E) Monitor the reactor inlet and outlet temperatures on adjacent channels of the Sanborn Recorder. With all shim rods completely inserted, record the Veeder counter readings on a data sheet with the format shown in Figure IV-2.

3. (O) Withdraw shim rods 1 and 4 completely. Withdraw shim rod 3 about 6 inches, which is about 960 V. U. Withdraw shim rod 2 until the reactor is critical and the power is at point "A." (Shim rod 2 will be withdrawn about 18 inches at criticality). Do not move shim rods 1, 2, or 4 during Steps 4 through 9.

4. (E) Record the Veeder counter readings for shim rods 1, 2, and 4. Set the scalers for the appropriate counting interval, as shown below. (Allow a three second recycle time for the Berkley-Beckman, and 0.5 seconds for the Systron).

Period to be Measured (sec)	Counting Interval (sec)
Greater than 120	25
70 - 120	10
30 - 70	5

Record all necessary information on the data sheet shown in Figure IV-2. Record on the printer tape the run number, counting time, cycle time, and resolution time. After the reactor power has been steady at "A" for 20 minutes, record the position of shim rod 3 on the data sheet and on the printer tape.

5. (O) After the reactor power has been steady at "A" for 20 minutes, withdraw shim rod 3 on the fast drive to obtain a period of about 200 seconds. All movement must cease before the neutron level has increased 1/2 decade in this and all the following period measurements.

6. (E) After rod motion has stopped, immediately start both scalers. Be sure that no rod is moved after counting has started. Record the new position of shim rod 3 (in V. U.).

7. (O, E) When the neutron level reaches point "T," stop the scalers and reduce the neutron level to point "A" using shim rod 3 only. Steady power at point "A." Do not move shim rods 1, 2, or 4.

> NOTE: It may be necessary to use another rod to reduce the neutron level quickly. If so, use shim rod 4 for this purpose. After the neutron level reaches "A," withdraw shim rod 4 to its previous position, and hold the power constant with shim rod 3.

Do steps 1 through 4 in part 1 of the analysis section.

8. Repeat steps 4 through 7, using a period of about 100 seconds in Step 5.

9. (O, E) Repeat Steps 4 through 6, using a period of about 30 seconds in Step 5.

10. (O) With the period of 30 seconds, when the neutron level reaches point "T," reduce power by driving in shim rod 4. Steady power at "A." Slowly adjust shim rod 3 until it is 6 inches (960 V. U.) above where it was in Step 4. While moving shim rod 3, use shim rod 4 to hold the power constant. DO NOT MOVE SHIM RODS 1 OR 2. After shim rod 3 is in place, adjust shim rod 4 for steady power.

11. (O, E) Repeat Steps 4 through 10. Continue repeating until shim rod 4 is completely inserted.

12. (O, E) After shim rod 4 is too far in to balance a 6-inch movement of shim rod 3, shim rod 2 will be used, with shim rod 4 completely in. Continue repeating Steps 4 through 10, using shim rod 2 instead of shim rod 4 in Step 10. After shim rod 2 is completely inserted, use shim rod 1. Continue until, at the end of Step 10, shim rod 3 is within 6 inches of the top of the core, i. e. 10,560 V. U. out.

Steps 13 and 14 will be used to calibrate shim rod 3 against the gang.

13. (O) After the above measurements are completed, steady reactor power at point "A." Then readjust the shim rods so that shim rods 1, 2, and 4 are ganged. The ganged shim rods should always be within 1 V.U. of each other. Make the final adjustment for criticality with shim rod 3. (The position of the ganged rods will be about 30 inches out.)

14. (O, E) Repeat the calibration of shim rod 3 as before (Steps 4 through 10), but use the three ganged rods instead of shim rod 4 (in Step 10), and step shim rod 3 in after each set of period measurements. Continue until shim rod 3 is within 6 inches (960 V.U.) of the bottom of the core. Connect the thermopile in R-50 to one of the Sanborn channels and position it at the midplane index mark. Steps 15 through 21 will be used to calibrate shim rods 1, 2, and 4 against shim rod 3.

15. (O) Steady reactor power at point "B." Readjust the shim rods so that shim rod 3 is about 6 inches out (960 V.U.), but shim rod 4 is completely out, and shim rods 1 and 2 are ganged. Adjust shim rod 3 for criticality.

> <u>NOTE</u>: The console operator can use either the Sanborn Recorder connected to the thermopile, the log N, or the electrometer to determine when the power is level.

16. (E) When the power has been steady at exactly point "B" for 10 minutes with no adjustment, record the Veeder counter readings on the data sheet shown in Figure IV-3.

17. (O) Gradually insert shim rod 4, and simultaneously withdraw shim rod 3. Keep the reactor power within 1/2 decade of point "B." When shim rod 4 has been inserted 6 inches, i.e. 960 V.U., steady reactor power at exactly point "B" with shim rod 3. Do not move the other two shim rods.

18. (E) After reactor power has been steady at point "B" for 10 minutes, without any rod motion, record the data required on the data sheet shown in Figure IV-3. (If a rod must be adjusted during the waiting period, start a new

waiting period.) Calculate the worth of the 6 inches of shim rod 4, which is equal to the change in reactivity associated with the movement of shim rod 3, as read from the integral worth curve with shim rods 1, 2, and 4 ganged.

19. (O, E) Repeat Steps 17 and 18 for another 6-inch insertion of shim rod 4. Continue repeating until shim rod 4 is completely inserted.

20. (O, E) After shim rod 4 is completely inserted, repeat Steps 15 through 19, using shim rod 1 in place of shim rod 4 (with shim rods 2 and 4 ganged). In addition, two sets of period measurements will be made with shim rod 1: at 36 inches out (5760 V.U.) and at 18 inches out (2880 V.U.). These measurements are needed to compare with later shim rod calibrations with the reactor oscillator. Make the two sets of period measurements in the manner given in Steps 4 through 10.

21. (O, E) Repeat Steps 15 through 19, using shim rod 2 in place of shim rod 4 (with shim rods 1 and 4 ganged). Steps 22 through 31 will be used to measure the integral worth of each of the safety rods.

22. (O) Bypass the necessary interlock so that the safety rods may be moved without all shim rods completely inserted, and so that the shim rods may be moved without all safety rods completely withdrawn.

23. (O) Readjust the shim rods so that shim rod 3 is about 6 inches (960 V.U.) out and shim rods 1, 2, and 4 are ganged. Adjust shim rod 3 for criticality, with the neutron level at exactly point "B."

24. (E) After the power has been constant at point "B" for 10 minutes without any rod motion, record the information required on the data sheet shown in Figure IV-4.

25. (O) Slowly insert safety rod 1, and hold the power approximately level by simultaneously withdrawing shim rod 3. The neutron level should not vary more than 1/2 decade about point "B." Continue until the safety rod is completely inserted. Do not move shim rods 1, 2, or 4.

26. (O, E) Adjust shim rod 3 for criticality, with the neutron level at exactly point "B." After the power has remained constant for 10 minutes with no rod motion, record the necessary information on the data sheet. Convert the change in position of shim rod 3 to change in reactivity from the measured integral worth curve of shim rod 3 (with shim rods 1, 2, and 4 ganged).

27. (O, E) Withdraw safety rod 1 and simultaneously insert safety rod 2. Keep the neutron level within 1/2 decade of point "B." When safety rod 1 is completely out and safety rod 2 is completely in, repeat Step 26.

28. (O, E) Withdraw safety rod 2 and insert safety rod 3, in the same manner as before. Then repeat Step 26.

29. (O, E) Withdraw safety rod 3 and insert safety rod 4 in the same manner as before. Then repeat Step 26.

30. (O, E) Withdraw safety rod 4, and simultaneously insert shim rod 3, holding the neutron level within 1/2 decade of point "B." When safety rod 4 is out, repeat Step 26.

31. (O, E) Proceed to the next experiment.

ANALYSIS OF PERIOD MEASUREMENTS

I. PRELIMINARY ANALYSIS OF DATA

One person from the Experimental Unit should analyze the data as they are being taken. The results of this analysis will show how good the data are, and whether any repeat measurements are necessary.

1. Using semilog paper, plot the data from the scaler-printer. Be sure to put the run number on the graph. The plot will be similar to Figure IV-5 for each period measurement. The number of counts will be plotted against the time at the beginning of each counting interval. Put this graph in the notebook.

2. Draw a straight line through the data as shown in Figure IV-5. Extend this line so that it covers two decades.

3. Divide the time required for the straight line to traverse two decades by 4.605. This gives the period. Record the period on the data sheet in Figure IV-2, and on the graph.

4. Find the reactivity corresponding to this period from the curves of reactivity *vs* period. These curves will be kept with the notebooks. The curves give reactivity in % $\Delta k/k$. Multiply by 1.43×10^2 to obtain reactivity in cents. Enter reactivity in cents on the data sheet.

5. As soon as the necessary data are available, calculate the difference in reactivity between the 100-second and 200-second periods, the difference in shim positions (in V. U.), and the shim rod worth in cents per 10 V. U. Also calculate the average position of shim rod 3, which is 1/2(position A + position B). Subtract from this the zero reading of shim rod 3. Plot the differential worth as a function of average rod position on a curve similar to Figure IV-6.

6. Do the same for the 30-second to 300-second and the 30-second to 100-second period comparisons as soon as the data are available.

7. It is very important that the data be analyzed as soon as possible, so that any questionable data will be detected and remeasured. Be sure that the engineer from the Experimental Unit sees each new point on the differential worth curve as soon as it is plotted.

8. The integral worth curve will be plotted concurrently with the differential curve. The value of the integral curve at a position x is equal to the area under the differential curve from 0 to x. This area can be measured with the polar planimeter.

II. IBM ANALYSIS OF DATA

1. Record on the print-out tape the run number, counting time, cycle time, and resolution time.

2. Duplicate the tapes. Paste the original in the notebook with the graph of the data described above.

3. On the duplicates, eliminate all points during the waiting time. Send the duplicates to the IBM Group at Rocketdyne (Dept. 592), along with a filled-out "Short Form Job Request."

4. Analyse the results of the IBM calculation by the method given in Steps 5, 6, and 8 above. Inspect the point-by-point comparison of the experimental data to the calculated curve. If any bad points are in evidence, eliminate those points, substitute good points, and send the data back to the IBM Group.

III. RE-ANALYSIS AFTER ISOTHERMAL TEMPERATURE COEFFICIENT MEASUREMENT

1. After the measurement of the isothermal temperature coefficient, the data can be corrected for any changes in temperature which occurred between two period measurements.

2. Multiply the change in the average of the reactor inlet and outlet primary sodium temperatures by the isothermal temperature coefficient. Subtract this quantity (which is positive) from the reactivity measured at the higher temperature.

3. Use the corrected reactivity in Steps 5, 6, and 8 in Part I.

ALTERNATE PROCEDURE

If the SRE neutron source can be removed after criticality is reached, the experiment can be performed more rapidly. The main procedure should be followed exactly, except for the following changes:

Step 3

Complete the step as given. Then withdraw the source six feet and keep the power constant by moving shim rod 2.

Steps 4 through 10

No period of 200 seconds will be used at any time. Instead, do the following: After the power has been steady at "A" for five minutes without any shim rod motion, start the scalers. Do not move any rod after the scalers begin counting. Continue for 15 minutes. Record the information required on the data sheet shown in Figure IV-2.

> NOTE: The reactor will probably be on a very long period, since exact adjustment for criticality is difficult. This is acceptable.

After 15 minutes, stop counting and reset the scalers for a 100-second period. Withdraw shim rod 3 on the fast drive to obtain a stable period of 100 seconds. Do Steps 6 and 7 as given in the main procedure. Do Steps 4, 5, 6, and 10 for a 30-second period.

Steps 11 through 14

No change, except that the above procedure is always used in place of the measurement with a 200-second period.

Steps 15 through 31

No change.

Analysis

No change is required, except in the treatment of the very slow period. The plot of counts vs time for this period should be made as before, and a straight line drawn through the points in the middle of the time interval. Extend the line until it completely traverses the graph paper. Take the two extreme points on the line; call the number of counts C_1 and C_2, and the respective times t_1 and t_2. Calculate the period by the relation:

$$\text{Period} = \frac{t_2 - t_1}{\ln C_2 - \ln C_1} ,$$

where ln is $\log_e$.

EXPECTED RESULTS

The shim rods will have about the same worth as in the first core:*

First Core Shim Rod Calibrations†

Shim Rod(s)	Total Worth (dollars)
1	3.00
2	2.62
3	3.07
4	2.49
All Four	10.00

The total worth will be less than the sum of the individual worths because of the shadowing between rods. Although the total worth will not be measured directly, it can be estimated from the individual worths, and from the difference in the worths of shim rod 3 in the two different configurations used.

The safety rod worth will also be about the same as in the first core, where the individual worths were between 1.79 and 2.40 dollars and the total worth was about 7.35 dollars.†

* A. I. Staff, "Hazards Summary for Thorium-Uranium Fuel in the Sodium Reactor Experiment," NAA-SR-3175 (Revised), July 1, 1959.

† R. W. Campbell, "Low Power Physics Experiments on the Sodium Reactor Experiment," NAA-SR-3341.

EXPECTED CONCLUSIONS

The results should buttress the technique for worth estimates in the Hazards Summary.*

APPENDIX

A. SCHEDULE

This experiment will begin after the completion of Experiment III, and will require approximately 7 days (21 shifts).

B. MANPOWER REQUIREMENTS

An engineer and an analyst from the Experimental Unit and the console operator for each shift will be required.

C. EQUIPMENT REQUIREMENTS

Two standard fission counters, the log count rate meters and recorders, and two automatic scalers with print-out devices connected and tested in Experiment III are needed. Also needed is a neutron-sensitive thermopile connected to a Sanborn Recorder.

D. CREDIBLE ACCIDENTS

None or the scram circuits will be bypassed during the experiment. Two interlocks must be bypassed, one to allow movement of the safety rods with the shim rods partially withdrawn, and the other to allow movement of the shim rods with the safety rods partially inserted. This will cause no hazard, since at least two safety rods will be completely withdrawn, and if a scram signal occurs, all safety rods will drop, including any which may be partially withdrawn.

Since the transient periods are shorter than the stable periods, the short period alarm may occasionally be tripped, particularly while pulling rods for a 30-second period. However, if the period drops below 10 seconds, a setback will be automatically initiated, and at 5 seconds the reactor will scram.

* A.I. Staff, "Hazards Summary for Thorium-Uranium Fuel in the Sodium Reactor Experiment," NAA-SR-3175 (Revised), July 1, 1959.

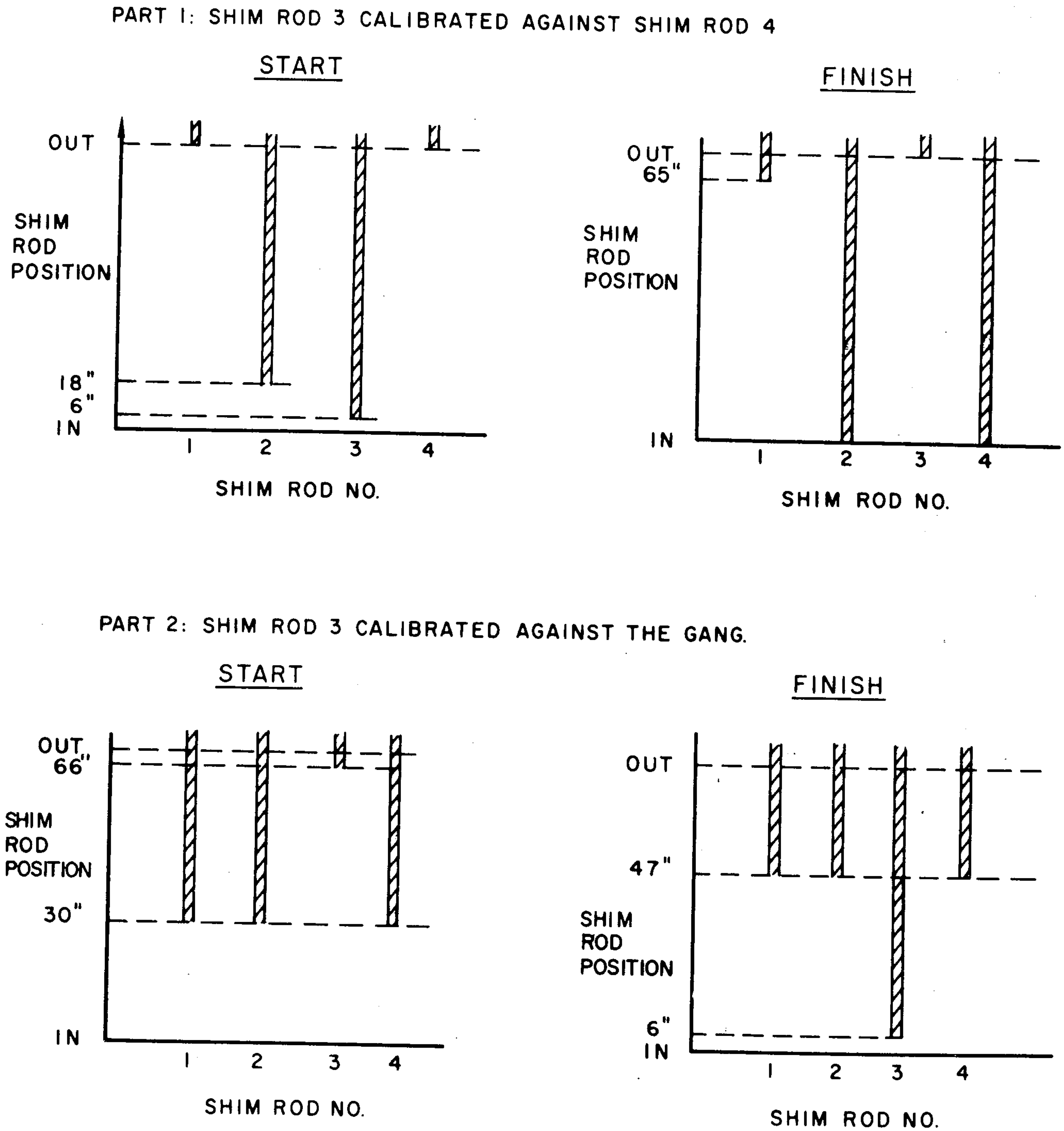


Figure IV-1. Approximate Positions of Shim Rods for Calibration of Shim Rod 3

Run No.		0	1A	1B	1C	2A	2B	2C, etc.
1. Shim Rod Positions (V.U.)	Shim Rod 1							
	Shim Rod 2							
	Shim Rod 4							
2. Initial Position of Shim Rod 3								
3. Initial Reading of Log N (or log count rate meter)								
4. Primary Sodium Temperature (°F)	Reactor Inlet							
	Reactor Outlet							
	Average							
5. Primary Flow Rate (gpm)								
6. Final Position of Shim Rod 3								
7. Final Reading of Log N (or log count rate meter)								
8. Period (sec)								
9. Reactivity (cents)								

Comparison Between:	1B-1A	1C-1A	1C-1B	2B-2A	2C-2A	2C-2B, etc.
Difference in Shim Rod 3 Position (V.U.)						
Difference in Reactivity (cents)						
Differential Worth (¢/10 V.U.)						
Avg. Shim Rod 3 Position						

Run O - Position of shim rods at lower limits
Run A - Slow Period
Run B - Medium Period
Run C - Fast Period

Figure IV-2. Data Sheet for Shim Rod 3 Calibration

Run No.		1	2	3	4	5	6	7	8	etc.
Gang Positions*	Shim Rod 1									
	Shim Rod 2									
Primary Na Temperature (°F)	Reactor Inlet									
	Reactor Outlet									
	Average									
Primary Flow (gpm)										
Log N Reading										
Shim Rod 3 Position*										
Shim Rod 4 Position*										
Change in Shim Rod 3 Position*										
Reactivity Worth†										
Change in Shim Rod 4 Position*										
Accumulated Change in Reactivity										

*All shim rod positions in V.U.

†Obtained from the integral worth curve of Shim Rod 3 calibrated against the gang

Figure IV-3. Data Sheet for Shim Rod 4 Calibration

Run No.		1	2	3	4	5	6
Gang Positions*	Shim Rod 1						
	Shim Rod 2						
	Shim Rod 4						
Primary Na Temp, (°F)	Reactor Inlet						
	Reactor Outlet						
	Average						
Primary Flow (gpm)							
Log N Reading							
Safety Rod Positions (In or Out)	No. 1	Out	In	Out	Out	Out	Out
	No. 2	Out	Out	In	Out	Out	Out
	No. 3	Out	Out	Out	In	Out	Out
	No. 4	Out	Out	Out	Out	In	Out
Shim Rod 3 Position*							
Change in Shim Rod 3 Position*							
Reactivity Worth†							

*All shim rod positions in V.U.

†Obtained from the integral worth curve of Shim Rod 3 calibrated against the gang.

Figure IV-4. Data Sheet for Safety Rod Calibration

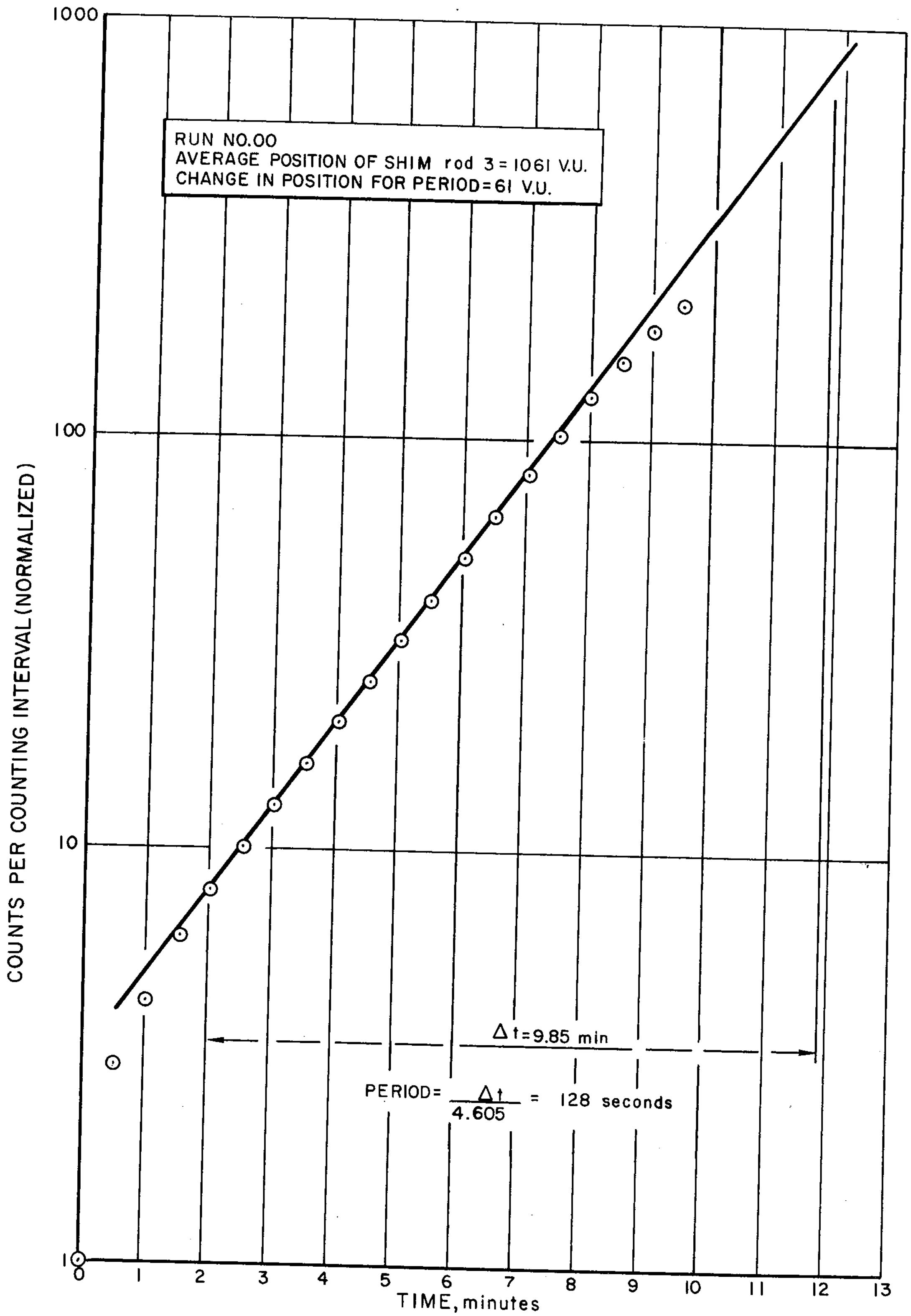


Figure IV-5. Sample Plot of Count Rate vs Time

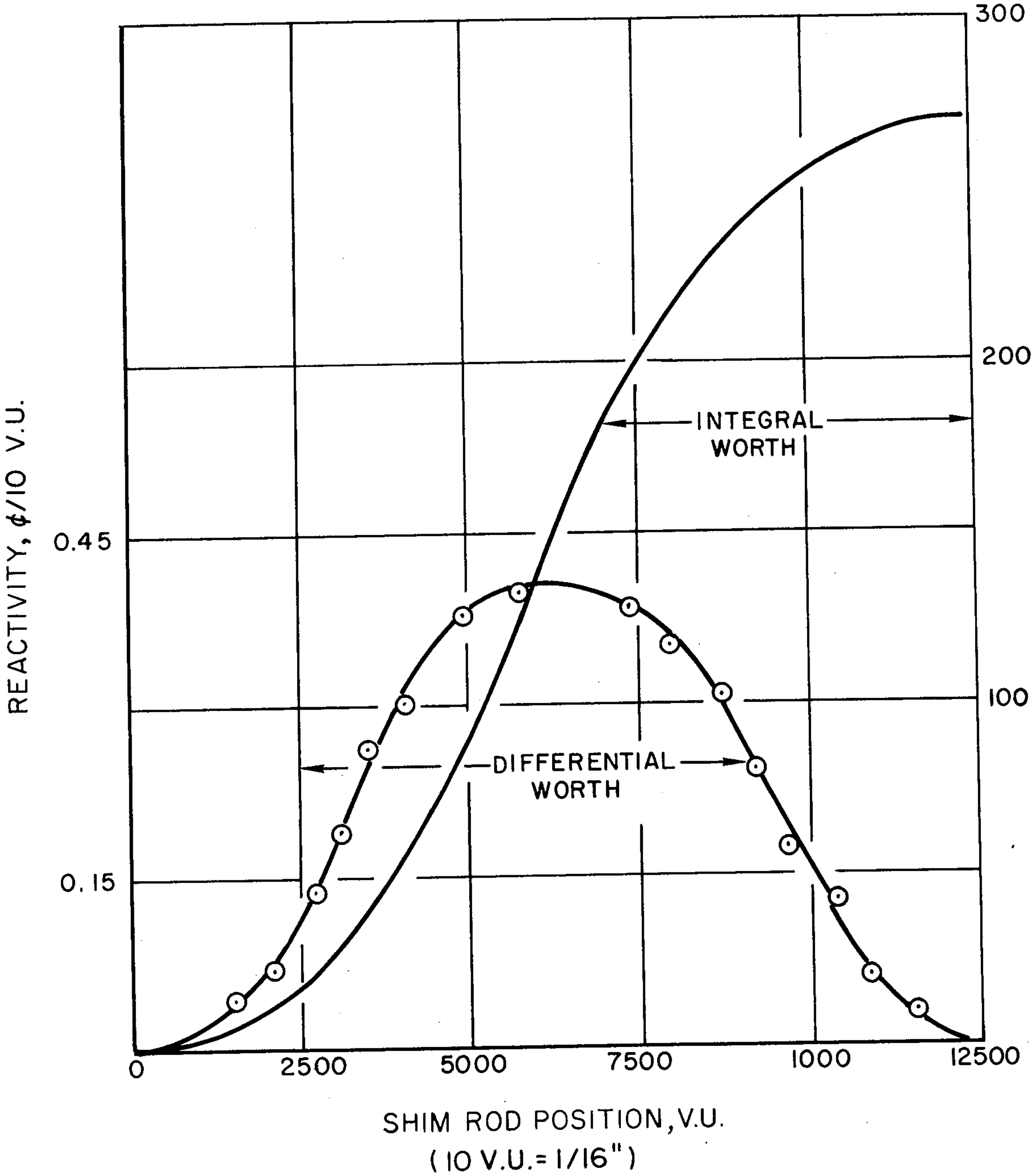


Figure IV-6. Sample Plot of Shim Rod Worth Curves

V

REACTOR OSCILLATOR MEASUREMENTS

By
R. W. KEATEN

CONTENTS

TABLES

FIGURES

OBJECTIVE

The reactor oscillator will be used to measure the zero power transfer function. It will also be used to measure the differential worth of shim rod 1 at two positions. This worth will then be compared with that obtained from period measurements at the same two positions.

PURPOSE

The calibration of shim rod 1 with the oscillator will be done at low power to demonstrate the feasibility of high-power rod calibrations with the oscillator. The measurement of the zero power transfer function will yield the value of ℓ/β, the ratio of prompt neutron lifetime to the effective fraction of delayed neutrons. The zero power transfer function is also needed for comparison with the at-power transfer function to measure the power coefficient of the SRE.

METHOD

I. THEORY

If the reactivity of a reactor is varied sinusoidally about the critical point, i.e.,

$$\rho = \delta\rho \sin\omega t,$$

then the response of the neutron density, n, will also be sinusoidal about some average value n_o:

$$n(t) = n_o + |\delta n| \sin(\omega t + \theta),$$

where $|\delta n|$ is the magnitude of the resulting variation and θ is the phase angle between the reactivity and the neutron density. $|\delta n|$ is a function of ρ and ω, and θ is a function of ω.

The standard reactor kinetics equations can be solved for a sinusoidal variation in reactivity. The solution is conveniently expressed in terms of the transfer function, $G(j\omega)$. This function, also called the frequency response, contains a real and an imaginary part. Its amplitude is equal to the magnitude of $|\delta n|/n_o$ per unit variation of reactivity (in dollars), and its phase angle is equal to θ. The equation for $G(j\omega)$ is found by using Laplace Transforms. The result (for zero power) is

$$G(j\omega) = \frac{|\delta n|/n_o}{\delta\rho/\beta} \angle\theta = \frac{1}{\frac{j\omega\ell}{\beta}\left[1 + \sum_{i=1}^{6} \frac{\beta_i/\beta}{\frac{\ell}{\beta}(j\omega + \lambda_i)}\right]}, \qquad \ldots(1)$$

where

β = effective fraction of delayed neutrons,

β_i = effective fraction of delayed neutrons in the i^{th} group,

ℓ = prompt neutron lifetime,

λ_i = decay constant of the i^{th} group,

$j = \sqrt{-1}$.

Theoretical plots of $G(j\omega)$ at zero power for several values of ℓ/β are shown in Figure V-1, based on the Keppin and Wimett data for delayed neutrons.*

If the frequency of oscillation is high enough so that $\omega >> \lambda_i$, then the expression for $G(j\omega)$ reduces to

$$G(j\omega) = \frac{|\delta n|/n_o}{\delta\rho/\beta} \angle\theta = \frac{1}{j\omega\frac{\ell}{\beta} + 1} \quad . \qquad \ldots(2)$$

By measuring $G(j\omega)$ in this range, we can determine ℓ/β.

For shim rod calibrations, the oscillation frequency is 0.05 cps. At this

*G. R. Keppin and T. F. Wimett, "Reactor Kinetic Functions: A New Evaluation," Nucleonics, October, 1958.

point, $G(j\omega)$ is independent of ℓ/β, as shown in Figure V-1, and is also insensitive to the values of λ_i and β_i/β.

II. DESCRIPTION OF OSCILLATOR

A circuit diagram of the reactor oscillator apparatus is shown in Figure V-2. Dotted lines represent mechanical connections and solid lines are electrical connections. Figure V-3 shows a layout of the drive mechanism. M_1 is the main drive motor, with a variable speed controlled by C_1 and by three gear reducers (not shown in Figure V-2). For shim rod calibrations, the motor is connected to a scotch yoke gear mechanism, which is attached to one of the shim rod drives. The scotch yoke translates the rotary motion of the motor to a sinusoidal motion.

For measurement of the transfer function, M_1 is connected to a rotor. The rotor and a stator are located in an instrument thimble in Channel R-49. The variation in reactivity is provided by the change in shadowing of boral chips on the rotor and stator as the rotor turns. The chips are shaped to give a sinusoidal variation in reactivity with a constant motor speed.

The motor M_1 also drives sine and cosine signal-generating potentiometers, P_1, P_2, and P_3. Zero adjustment of the phase of the signals from P_1 and P_2 is made with the differential gear D_2, which is moved with the motor M_2, controlled by C_2. D_3, M_3, C_3, and P_3 are not used in this experiment.

The neutron flux density is detected with a gamma-compensated ion chamber and amplified with a Keithley micro-microammeter. The steady state signal, n_o, is eliminated by a bucking voltage adjusted by HP_1. The first amplifier, A_1, adds the signal from the Keithley ammeter to the bucking voltage, and amplifies the sum, which is δn. A_2 serves only as an inverter. The signal from A_1 goes to the positive side of P_1, and the signal from A_2 goes to the negative side.

In P_1, the input signal is multiplied in one branch by $\sin \omega t$ and in the other branch by $\cos \omega t$. These multipliers are exactly in phase with the variation in reactivity. The two output signals from P_1 are then integrated in the two circuits containing A_3 and A_4, and the outputs from the integrators are read out on Sanborn Channels 3 and 4. The sine wave generated by P_2, which is also in phase with the variation in reactivity, is read out on Channel 1, and the signal from A_1 (which is δn) is shown on Channel 2.

III. METHOD OF SHIM ROD CALIBRATION

The scotch yoke assembly will be attached to shim rod 1, which will be raised to the reactor midplane, with the hand crank shown in Figure V-3. Sine pots P_1 and P_2 will be adjusted to be in phase with the shim rod motion. Then the reactor will be made critical, shim rods 2 and 4 adjusted to a common level, and shim rod 3 adjusted for criticality. When the flux level is constant, shim rod 1 will be oscillated with a frequency of 0.05 cps. Then shim rod 1 will be inserted until it is about 21 inches out and again oscillated.

The change in reactivity will be calculated from

$$\frac{\delta\rho}{\beta} = \frac{|\delta n|/n_o}{|G(j\omega)|} ,$$

where $\delta\rho$ refers to the change in reactivity caused by moving shim rod 1 from its midpoint to either extreme. $|G(j\omega)|$ is the calculated amplitude of the transfer function at 0.05 cps, and is 1.38. $|\delta n|/n_o$ will be obtained as described in Subsection V, below.

IV. METHOD OF TRANSFER FUNCTION MEASUREMENT

The rotor and stator will be installed in Channel R-49 and the drive mechanism connected to the rotor. The reactor will be made critical and sine pots P_1 and P_3 will be adjusted to be in phase with the reactivity variation generated by the rotor. Oscillation will start at 0.05 cps, be increased to 20 cps, and then decreased to 0.001 cps. Five measurements will be made in each frequency decade. The amplitude and phase of $G(j\omega)$ will be obtained as described in Subsection V. The measured curves of amplitude and phase angle <u>vs</u> frequency will be compared with the calculated curves to determine the value of ℓ/β.

V. METHOD OF ANALYSIS

The signal entering P_1 (see Figure V-2) is composed of the fundamental terms, which are desired, plus higher harmonics introduced by the system. This signal can be expressed as a Fourier Series; i.e.,

$$S(t) = |\delta n| \sin(\omega t + \theta) + \sum_{m=2}^{\infty} A_m \sin(m\omega t + \theta_m),$$

where δn and θ are the amplitude and phase angle of the fundamental and A_m and θ_m are the amplitude and phase angle of the m^{th} harmonic. In one branch, this signal is multiplied by $\sin(\omega t)$ and then integrated from 0 to t. This integral, which is the input to the Sanborn Recorder on Channel 4, is

$$I_4(t) = |\delta n| \int_0^t \sin(\omega t + \theta) \sin \omega t \, dt + \sum_{m=2}^{\infty} A_m \int_0^t \sin(m\omega t + \theta_m) \sin \omega t \, dt .$$

Since the functions $\sin(m\omega t)$ are orthogonal, all terms under the summation are zero when the integration is over an integral number of cycles. The integral of the fundamental gives

$$I_4(t) = |\delta n| \left(\frac{\cos\theta}{2} t + C_1 \sin^2 \omega t - C_2 \sin 2\omega t \right),$$

and if the integral is over an integral number of cycles, the terms containing C_1 and C_2 are zero, so that

$$I_4 = |\delta n| \frac{(\cos\theta)t}{2} .$$

In the same way, the integral in Channel 3 becomes

$$I_3 = |\delta n| \frac{(\sin\theta)t}{2} .$$

These forms for I_3 and I_4 are the equations for the straight lines shown in Figure V-4. T_3 and T_4 are the time intervals used in the analysis.

The slopes of the straight lines are

$$M_3 = I_3/T_3 = |\delta n| \frac{\sin\theta}{2},$$

$$M_4 = I_4/T_4 = |\delta n| \frac{\cos\theta}{2}.$$

Hence we obtain for the desired results:

$$|\delta n| = 2(M_3^2 + M_4^2)^{1/2}$$

and

$$\tan\theta = M_3/M_4 .$$

n_o is obtained by measuring the bucking voltage necessary to eliminate the steady-state component. This is measured on the Sanborn Recorder, so that $|\delta n|$ and n_o have the same units (volts).

OUTLINE OF PROCEDURE

Part I: Calibration of Shim Rod 1

A. Set up oscillator and connect it to shim rod 1.

B. Withdraw shim rod 1 by hand to 38 inches.

C. Adjust sine pots P_1 and P_2.

D. Start up reactor.

E. Oscillate shim rod at 0.05 cps.

F. Insert shim rod to 21 inches and oscillate.

G. Shut down reactor and remove equipment.

Part II: Transfer Function Measurement

A. Install rotor and stator in Channel R-49 and set up oscillator.

B. Start up reactor.

C. Adjust sine pots P_1 and P_2.

D. Oscillate at 0.05 cps.

E. Raise frequency of oscillation to 20 cps, and then down to 0.001 cps, oscillating at 1, 1.5, 2, 5, and 8 in each decade.

F. Shut down reactor and remove equipment.

Part III: Analysis of Data

A. Calculate $|\delta n|$ and θ.

B. For shim rod calibration, calculate $\delta\rho/\beta$ and differential rod worth in cents per 10 V.U.

C. For transfer function measurements, calculate $|G(j\omega)| = \frac{|\delta n|/n_o}{\delta\rho/\beta}$ and plot $|G(j\omega|$ and θ vs ω.

PROCEDURE

The procedure should be followed exactly. Do all steps in the order given. Any deviation will result not only in loss of time and data, but may cause damage to the equipment. Use one copy of this procedure as a check list to make sure that each step is done. If any questions arise, contact C. W. Griffin and R. W. Woodruff before proceeding.

The notation in the procedures (A_1, S_3, etc.) corresponds to that in Figure V-2. The equipment is also labeled in the same manner.

I. CALIBRATION OF SHIM ROD 1

A. Oscillator Setup

1. (E) Roll the oscillator drive mechanism into the high-bay area close to the loading face, and take the oscillator off of the carriage. Move the oscillator rack and a 4-channel Sanborn Recorder into the high-bay area. Make the electrical connections listed in Table V-1, and then check the items in the preoperational check list given in Table V-2.

2. (E) Turn on the power to the operational amplifiers (A_1, etc.) by plugging in the power line to the oscillator rack. These amplifiers must be allowed a 4-hour warmup period before use. After any short power loss, allow a 30-minute warmup period.

<u>NOTE</u>: Under certain conditions these amplifiers can oscillate. This oscillation will show up on the corresponding voltmeter (V_1, etc.). To stop the oscillation, do the following:

1) For A_1 or A_2, close SS-1 or SS-2

2) For A_3 or A_4, turn S_5 or S_6, respectively, to the "short" position.

If the above methods do not stop the oscillation, pull the amplifier out of the rack. This cuts off the power to it, so allow it to warm up after replacing it in the rack.

TABLE V-1

OSCILLATOR CONNECTIONS

Make the following connections:

1. From the connector on the oscillator rack (on the back) marked "A_1 OUTPUT" to the input of Sanborn Channel 2.

2. From the connectors on the oscillator rack marked "A_1 OUTPUT" and "A_2 OUTPUT" to the connectors on the drive mechanism marked "P_1 +" and "P_1 -", respectively.

3. From the connector on the drive mechanism marked "P_1 - COS" to the connector on the oscillator rack marked "A_3 INPUT".

4. From the connector on the drive mechanism marked "P_1 - SINE" to the connector on the oscillator rack marked "A_4 INPUT".

5. From the connector on the drive mechanism marked "P_2 - SINE" to the input of Sanborn Channel 1.

6. From the connector on the oscillator rack marked "A_3 OUTPUT" to the input of Sanborn Channel 3.

7. From the connector on the oscillator rack marked "A_4 OUTPUT" to the input of Sanborn Channel 4.

8. Connect the two 1.5 Volt batteries across P_2, as shown in Figure V-2.

9. Connect a line from earphones at the Sanborn Recorder to earphones on the console.

10. From the connector on the back of the Keithley ammeter marked KEITHLEY OUTPUT" to the connector below marked "A_1 INPUT".

11. From the ionization chamber in instrument Channel VIII to the connector on the Keithley ammeter marked "KEITHLEY INPUT".

TABLE V-2

PREOPERATIONAL CHECK LIST FOR OSCILLATOR EQUIPMENT

1. S_1, S_2, S_5, and S_6 turned off. SS-1 and SS-2 opened.
2. Sanborn Recorders - Channels 1, 2, 3, and 4:
   a. AC-DC preamplifiers installed in all four channels.
   b. Turned on and calibrated to read 50 mv per cm.
   c. Charts running, and the "POSITION" knobs adjusted so that the pens are in the center of the charts.
   d. "ATTENUATOR RANGE" switches turned to "OFF" position.
   e. "ZERO SUPPRESSION" helipots turned to zero, and the toggle switches beneath them turned to the "OUT" position.
3. Toggle switch on C_1 (on the oscillator drive mechanism) turned off, and the helipot on C_1 turned to zero.
4. Switch (on the back of the oscillator rack) marked "A_1 GAIN" set at 10.

3. (O) Shut down the reactor. Be sure that shim rod 1 is all the way in. Maintain the average of the inlet and outlet sodium temperatures at 340°F by using the process line heaters, and if necessary, the pool heaters. Maintain the main primary sodium flow at 1000 gpm.

4. (E) Read the Veeder counter on the drive motor of shim rod 1, and record the data on a data sheet having the format shown in Figure V-5.

5. (O) Remove the drive mechanism from shim rod 1.

6. (E) Record on the data sheet the reading of the Veeder counter which is on shim rod 1 below the loading face.

7. (E) Connect the oscillator driving-mechanism to shim rod 1 as follows (see Figure V-6): First put the oscillator connector into the receptacle for the shim rod. Push it down as far as possible (it is spring loaded) and bolt it to the loading face as shown in the figure. The flange on the connector must be tight against the loading face. Attach the stub shaft.

8. (E) Move the oscillator onto the loading face, with the scotch yoke centered over the connector. Turn the hand crank until the Veeder counter reads zero, then attach the connecting shaft to the shaft on the bottom of the scotch yoke.

8. (E) With the clutch disengaged, i.e. with the black knob on top of the scotch yoke pulled up and the support in place, turn the hand crank slowly until the keyway on the connector engages the key on the shim rod gear. Before any further movement, record the reading of the Veeder counter and the pointer on the top of the scotch yoke. This must be recorded at exactly this point, with the key in place but before the shim rod driving gear has been moved.

B. Movement of Shim Rod 1 to First Position

1. (E) Withdraw shim rod 1 by turning the hand crank counter-clockwise. Continue until the shim rod is 1520 oscillator Veeder units (O. V. U.)* above the bottom position. At this position shim rod 1 is about one-half of the way out.

*One O. V. U. is a change of one unit in the last digit of the Veeder counter on the scotch yoke, and corresponds to 1/40-inch linear motion of the shim rod.

2. (E) Turn the hand crank until the pointer is on zero. Turn the main drive shaft by hand until the rack inside the scotch yoke is in the center. Then engage the clutch. This connects the main drive shaft through the scotch yoke to the connecting shaft.

3. (E) Turn the hand crank clockwise as far as possible. The pointer will rotate to its maximum displacement. Record on the data sheet the number of degrees that the pointer moved. Move the pointer back to zero, then turn it as far counter-clockwise as possible, and record the number of degrees moved. The midpoint between the two maximum displacements is the exact center of motion. Place the pointer on this midpoint position and record on the data sheet the position of the pointer and the Veeder counter reading.

C. Adjustment of the Sine Potentiometers

1. (E) Turn the RANGE switch on the Sanborn Channel 1 to 2 volts/mm (which is minimum sensitivity).

2. (E) Connect the drive shaft to M_1 through any of the gear reducers, to help hold the drive shaft steady. This shaft must not turn during the following step.

3. (E) Slowly change the setting of C_2 while watching the reading on Sanborn Channel 1. This turns M_2, which changes the setting of D_2 and thus alters the phase of P_1 and P_2. Be sure that the shaft to P_1 turns the same direction that it does when driven from the main drive shaft. Continue until the pen on channel 1 is in the center, then increase the gain on Channel 1, and readjust the sine potentiometers. Continue the adjustments until the pen on Channel 1 is in the center with maximum gain on the channel, then reduce the gain to the minimum value.

D. Reactor Startup

1. (O) Make the reactor critical, and raise the power until the Keithley ammeter reads 70% of full scale on the "10×10^{-8}" scale. At this point, the log N recorder should be between points "A" and "B." If it is not, contact R. W. Woodruff.

2. (O) Adjust shim rods 2 and 4 until they are at the position which they occupied in Step 14 of Experiment IV. Adjust shim rod 3 for criticality.

3. (O) Maintain temperatures and flow as in Step A-3.

4. (E) Record the temperatures and flow required on the data sheet.

E. Rod Oscillation

1. (E) When the power level is steady, record the log N reading and the positions of shim rods 2, 3, and 4. Then close S_1 and record the readings of V_1 and V_2. These should have the same magnitude but opposite sign.

2. (E) Close S_2, and turn up HP_1 to obtain the bucking voltage. When both V_1 and V_2 read zero, turn the range switch on Channel 2 to 2 volts/mm. Adjust HP_1 until the pen on Channel 2 is in its original position with maximum gain on the channel. Then reduce the gain on Channel 2 to the minimum value.

3. (E) Be sure that the switch on C_1 is off, then plug in the power to C_1 and turn on the switch. Allow at least a 2-minute warmup period. Set the gear reducers for 100-to-1 reduction, as shown in Figure V-7.

4. (E) When the controller is warmed up, notify the console operator that the oscillations are starting. Then slowly turn the helipot on C_1 until it reads 91. This gives a motor speed of 5 cps.

5. (O) The console operator will eliminate the reactor drift induced by the oscillation by moving shim rod 3. He will be advised through earphones by the analyst at the Sanborn Recorder. The Sanborn Recorder is connected to the Keithley ammeter, which is more sensitive than the process instrumentation.

6. (E) When the power is level, record the average reading of the log N and the position of shim rod 3 on the data sheet.

7. (E) While the reactor is being adjusted, increase the gain of Sanborn Channels 1 and 2 to give as large a signal as possible. After reading the paragraph below, close S_5 and S_6.

IMPORTANT: Any time that S_5 and/or S_6 are closed, watch V_3 and V_4. When the reading on either one reaches 30 volts (positive or negative), push in S_3 or S_4, as required. Hold it in until the reading on the voltmeter has dropped to zero. This shorts the integrating condenser and prevents overloading of the amplifier. (Also short the condenser when the pen on the Sanborn Recorder reaches the edge of the chart, which will usually happen before the voltmeter reads 30 volts.)

8. (E) Adjust HP_1 to make the oscillations on Channels 3 and 4 uniform, and of minimum amplitude. Then adjust the gain of these channels so that at least five peaks are formed before the pen reaches the edge of the chart.

9. (E) When all adjustments have been made and the reactor power is steady, tell the console operator that a run is starting. Turn on the timing mechanism on the Sanborn Recorder, then short the condensers, i.e. push in S_3 and S_4 and release them.

10. (O, E) The console operator always has manual control of the reactor. No rod should be moved while a run is being made unless absolutely necessary. However, if a rod is moved, immediately notify the Experimental Unit engineer, and the run will be repeated.

11. (E) The following conditions must be satisfied for any run to be valid:

a) The size of the oscillations on Channels 3 and 4 must not vary during the run.

b) At least five peaks must be seen on both Channels 3 and 4.

c) No significant reactor drift should occur during the run.

d) Shim rods 2, 3, and 4 should not be moved during the run.

If any of these conditions is not satisfied, repeat the run and continue repeating until satisfactory data are obtained.

NOTE: In general, the size of the oscillations on Channel 3 will not be the same as the size of those on Channel 4. Also, the slopes of the lines will not be the same. This is expected. The important thing is to be sure that the sizes of the oscillations and slopes of the lines do not change.

12. (E) When a good run has been obtained, record on each Sanborn chart the run number, the position of shim rod 1, the setting of the "RANGE" switch on that channel, and the start and finish positions of the run. Tape in the notebook the portions of the charts containing the good run. Discard the portions containing unusable data. Record all required information on the data sheet.

13. (E) Continue to oscillate the rod. Open S_5 and S_6, and then short the condensers. This removes the signals on Channels 3 and 4.

14. (E) Turn the switch marked DC ZERO SUPPRESSION on Channel 2 to the "IN" position. Then turn up the helipot above this switch and simultaneously turn down HP_1, keeping the signal on Channel 2 at approximately the same point. This moves the bucking voltage from the external circuit to the Sanborn Recorder. Continue until HP_1 reads zero and the signal on Channel 2 is in the center of the chart, then record the reading of the helipot on the Sanborn Recorder on the data sheet, and on Sanborn charts 3 and 4. Also record the reading in volts (see Part III, Step A-7). The reading should be approximately equal to that of V_1 and V_2 in Step E-1. If necessary, repeat the run.

15. (E) Analyze the data to get the differential worth of shim rod 1 at this position. Follow the procedure for analysis given in Part III, Sections A and B. Compare this worth with that obtained earlier by period measurements. It the two agree within experimental error, proceed. If they do not, contact R. W. Woodruff.

16. (E) Put the electronic equipment back in its original condition; i. e., repeat items 1, 2, and 4 in Table V-2. Notify the console operator that rod oscillation is being stopped. Then turn down the helipot on C_1 slowly, being careful to stop the pointer in its midpoint position (the position recorded in Step B-3). Leave the switch on C_1 in the "ON" position.

17. (O) When oscillation stops, adjust the position of shim rod 3 to keep the power level constant.

F. Second Oscillation of Shim Rod 1

1. (E) Be sure all tension is off the drive shaft, then disengage the clutch on the scotch yoke. Tell the console operator that shim rod 1 will be driven in by hand, then slowly turn the hand crank clockwise to drive in the rod. Do not move the drive shaft. Continue until the rod is 840 O. V. U. above the bottom position. Stop the pointer in excactly the same position as in Step B-3. Sine pots P_1 and P_3 will be correctly adjusted only if the pointer reads the same as before. When the pointer is in the correct position, re-engage the clutch. (Before re-engaging, check the position of the rack inside the scotch yoke to make sure the drive shaft has not moved.)

2. (O) Continuously adjust the position of shim rod 3 to keep the power approximately level while shim rod 1 is being moved to its second position. After shim rod 1 has reached the second position, steady the reactor power at the same level as before.

3. (O, E) Oscillate shim rod 1 at this position by following the procedure given in Section E. Analyze the data as before. Compare the result to the worth of shim rod 1 obtained from period measurement in this position. If the two measurements agree, the experiment is finished. If they do not, contact R. W. Woodruff.

G. Reactor Shutdown

1. (O) When the Experimental Unit engineer says that the experiment is finished, shut down the reactor.

2. (E) Drive in shim rod 1 by disengaging the clutch and turning the hand crank clockwise. Go slowly, particularly near the bottom.

3. (E) Stop the shim rod in the same position as in Step A-9. Disconnect the oscillator mechanism and remove it from the high-bay area.

4. (O) Connect the drive motor to shim rod 1. Be sure that the Veeder counter on the shim rod drive reads the same as in Step A-4.

II. TRANSFER FUNCTION MEASUREMENT

A. Oscillator Setup

1. (E) Roll the oscillator drive mechanism into the high-bay area close to the loading face, and take the oscillator off of the carriage. Move the oscillator rack and the 4-channel Sanborn Recorder into the high-bay area. Make the electrical connections listed in Table V-1, and check all items listed in Table V-2.

2. (E) Turn on the power to the operational amplifiers (A_1, etc.) by plugging in the power line to the oscillator rack. These amplifiers must be allowed a 4-hour warmup period before use. After any short power loss, allow a 30-minute warmup period.

3. (O) Maintain the average of the reactor inlet and outlet sodium temperatures at 340°F by using the process line heaters, and, if necessary, the pool heaters. Maintain the main primary sodium flow at 1000 gpm.

4. (O) Remove the dummy assembly from Channel R-49. Insert the special thimble containing the oscillator rotor and stator.

5. (E) Connect the oscillator drive mechanism to the rotor as follows (see Figure V-8): Place the oscillator connector in the thimble. Push it down as far as possible (it is spring loaded) and then bolt it to the loading face as shown in the figure. The flange on the connector must be tight against the loading face. Attach the stub shaft to the oscillator connector.

6. (E) Unbolt the box containing the scotch yoke and remove it. Put on the support frame and 4-to-1 gear reducer as shown in the figure. Then move the oscillator onto the loading face with the gear reducer centered over the thimble. Attach the stub shaft to the shaft on the bottom of the gear reducer. Turn the connecting shaft by hand until the key engages the keyway on the rotor.

7. (E) Record the central metal temperature and fuel-channel exit temperature of one fuel element on adjacent Sanborn channels (do not use Channels 1, 2, 3, or 4).

B. Reactor Startup

1. (O) Make the reactor critical and raise the neutron level until the Keithley ammeter reads 70% at full scale on the "10×10^{-8}" scale. The power should be between points "A" and "B" on the log N recorder. (If it is not, contact R. W. Woodruff.) Adjust all four shim rods to the same position, and level the power. Connect the electrometer output to the flux controller, and put shim rod 3 on automatic control.

C. Adjustment of the Sine Potentiometers

1. (E) Before the sine pots can be adjusted, it is necessary to find the maximum, minimum, and zero positions of the rotor. To do this, slowly turn the drive shaft (with the drive motor M_1 disconnected from the shaft) and observe the position of shim rod 3, which is on automatic control. Record the maximum and minimum positions of shim rod 3 on a data sheet with a format as in Figure V-9. There are four maxima and four minima in one complete turn of the rotor. When the rotor positions for maximum, minimum, and null have been determined, mark the positions on the rotor protractor face. Set the rotor on one of the null positions.

2. (E) Turn the RANGE switch on Sanborn Channel 1 to 2 volts/mm (which is minimum sensitivity). Connect the drive shaft to M_1 through any of the gear reducers to help hold the drive shaft steady. This shaft must not move during the following step.

3. (E) Slowly change the setting of C_2 while watching the reading on Sanborn Channel 1. This turns M_2 which changes the setting of D_2 and thus alters the phase of P_1 and P_2. Be sure that the shaft to P_1 turns in the same direction that it does when driven from the main drive shaft. Continue until the pen on Channel 1 is in the center, then increase the gain on the Sanborn Recorder and readjust P_1 and P_2. Continue adjusting until the pen on Channel 1 is in the center with maximum gain on Channel 1, then reduce the gain to the minimum value. The sine signals from P_1 and P_2 are now in phase with the reactivity change generated by the rotor.

D. Oscillation at 0.05 cps

1. (E) Close S_1 and record the readings of V_1 and V_2 on the data sheet (Figure V-9). These should have the same magnitude but opposite signs.

2. (E) Close S_2 and turn up HP_1 to obtain the bucking voltage. When both V_1 and V_2 read zero, close S_8. Adjust HP_1 until the pen on Sanborn Channel 2 is in its original position with maximum gain on the channel. Then reduce the gain to the minimum value.

3. (E) Be sure that the switch on C_1 is off, then plug in the power to C_1 and turn on the switch. Allow at least a 2-minute warmup period. Set the gear reducers for 100-to-1 reduction, as shown in Figure V-7.

4. (E) When the controller is warmed up, notify the console operator that the oscillations are starting. Then slowly turn the helipot on C_1 until it reads 91. This gives a motor speed of 5 cps.

5. (O) Before the oscillations start, put the reactor on manual control. When the oscillations start, they will induce a small drift in the reactor power level. Adjust the position of shim rod 3 to eliminate the drift, as advised through the earphones by the analyst at the Sanborn Recorder.

6. (E) While the reactor is being adjusted, increase the gain of Sanborn Channels 1 and 2 to give as large a signal as possible. After reading the paragraph below, close S_5 and S_6.

IMPORTANT: Any time that S_5 and/or S_6 are closed, watch V_3 and/or V_4. When the reading on either one reaches 30 volts (positive or negative), push in S_3 or S_4, as required. Hold it down until the reading on the voltmeter has dropped to zero. This shorts the integrating condenser and prevents overloading the amplifier. (The condenser should also be shorted when the pen on the Sanborn Recorder reaches the edge of the chart, which will usually happen before the voltmeter reads 30 volts.)

7. (E) Adjust HP_1 to make the oscillations on Channels 3 and 4 uniform, and of minimum size. Then adjust the gain of these channels so that at least five peaks are formed before the pen reaches the edge of the chart.

8. (E) When all adjustments have been made and the reactor power is steady, tell the console operator that a run is starting. Turn on the timing mechanism to the Sanborn Recorder, then short the condensers; i.e., push in S_3 and S_4 and release them.

9. (O, E) The console operator always has manual control of the reactor. No rod should be moved while a run is being made unless necessary. However, if a rod is moved, immediately notify the Experimental Unit engineer, and the run will be repeated.

10. (E) The following conditions must be satisfied for any run to be valid:

a) The size of the oscillations on Channels 3 and 4 must not vary during the run.

b) At least five peaks must be seen on both Channels 3 and 4.

c) No significant reactor drift should occur during the run.

d) The shim rods should not be moved during the run.

If any of these conditions is not satisfied, repeat the run, and continue repeating until satisfactory data are obtained.

NOTE: In general, the size of the oscillations on Channel 3 will not be the same as the size of those on Channel 4. Also the slopes of the lines will be different. This is expected. The important thing is to be sure that the sizes of the oscillations and the slopes of the lines do not change.

11. (E) When a good run has been obtained, record on each Sanborn chart the setting of the RANGE switch on that channel, the position of the shim rods, and the start and finish positions of the run. Tape in the notebook the portion of the charts containing the good run. Discard the portion containing unusable data. Record all required information on the data sheet.

12. (E) Do not turn off the rotor. Open S_5 and S_6, and then short the condensers. This removes the signals on Channels 3 and 4.

13. (E) Turn the switch marked DC ZERO SUPPRESSION on Channel 2 to the "IN" position. Then turn up the helipot above this switch and simultaneously turn down HP_1, keeping the signal on Channel 2 at approximately the same level. This moves the bucking voltage from the external circuit to the Sanborn Recorder. Continue until HP_1 reads zero, then adjust the helipot on the Sanborn Recorder until the signal is at its original position. Record the helipot setting on the data sheet, and on the charts on Channels 3 and 4. The reading should be approximately equal to that read on V_1 and V_2 in Step D-1. If necessary, repeat the run.

14. (E) Analyze the data by the procedure given in Sections A and C of Part III. Plot the amplitude and phase of $G(j\omega)$ on a graph similar to Figure V-1. Compare the experimental value with the theoretical curve, and if these do not agree, contact R. W. Woodruff. Do this analysis before proceeding to the next run.

15. (E) If the agreement is satisfactory, put the electronic equipment back in its original condition: i. e., repeat items 1, 2, and 4 (Not 3) on the check list in Table V-2.

E. Oscillation at Different Frequencies

1. (E) Raise the frequency of oscillation stepwise to at least 20 cps. In each frequency decade, oscillate at 1, 1.5, 2, 5, and 8. The necessary settings of the helipot on C_1 are shown in Table V-3. For each oscillation follow the procedure of Section D. Always analyze the data for the last run before starting a new run.

2. (E) Make runs at as many frequencies as possible before changing the gear setting. Do not turn off the motor except when the gear setting is changed. The method of connecting the gears for 10-to-1, 100-to-1, or 1000-to-1 reduction is shown in Figure V-7. For frequencies above 6 cps, replace the 10-to-1 gear reducer by the 4-to-1 gear reducer, then set the gears as shown in Figure Figure V-7 for a 10-to-1 reduction. Return the reactor to automatic control during any gear changes or long delays. During any such delays, the rotor should rest at the neutral position.

3. (E) When the highest possible frequency has been measured, recheck the point at 0.05 cps. Then stepwise reduce the frequency, and in each decade oscillate at 1, 1.5, 2, 5, and 8. Go to as low a frequency as reactor drift will permit, probably about 0.001. For 10,000-to-1 (below 0.006), replace the 10-to-1 gear reducer with the extra 100-to-1 reducer, then set the gears as shown in Figure V-7 for a 1000-to-1 reduction. During oscillation at very low frequencies (0.01 cps or below), observe the central metal temperature of one fuel element, and one fuel-channel exit temperature, and record in the notebook the amplitude and if possible the frequency of any periodic variations. Label and save the Sanborn charts of temperature variations during good runs.

4. (E) It may be necessary to reduce the gain of A_1 at the low frequencies in order to keep the readings on Channels 3 and 4 on scale. If the amplitude of the signals on Channels 3 and 4 becomes too large to meet the conditions for a good run, change the setting of the A_1 GAIN switch to "1". Be sure that any changes are recorded in the log book, on the data sheet, and on the charts from Sanborn Channels 3 and 4.

TABLE V-3

DIAL SETTINGS FOR VARIOUS MOTOR SPEEDS

A. With 10-to-1, 100-to-1, 1,000-to-1, or 10,000-to-1 gear reduction.

Dial Setting	Motor Speed (cps)
91	5
143	8
177	10
253	15
328	20
477	30

B. With 4-to-1 gear reduction.

Dial Setting	Shaft Speed (cps)
364	5
572	8
608	10
1,000	15

5. (E) When the last run has been made, contact R. W. Woodruff before proceeding. The data must be analyzed and evaluated before the reactor is shut down.

F. Reactor Shutdown

1. (O) When the Experimental Unit engineer says that the experiment is finished, shut down the reactor.

2. (E) Disconnect the oscillator drive mechanism, the connecting shaft, and the oscillator-rotor connector, and remove all three from the high-bay area.

3. (O) Remove the rotor and stator and special thimble from the reactor. Then insert the corner channel dummy assembly.

4. (O, E) Proceed to the next experiment.

III. ANALYSIS

A. Calculation of $|\delta n|$ and θ

1. Take the charts from Sanborn Channels 3 and 4. These should be similar to Figure V-4. On each curve draw two straight lines, one tangent to the peaks and one tangent to the troughs, as shown in the figure.

2. Mark on the charts the longest time period possible during the good run. The periods do not have to be the same on the two charts.

3. For each channel, find an average value of I, in units of millimeters, as shown in Figure V-4. (The smallest division on the Sanborn chart is one millimeter.) Record the values on the data sheet. Convert the averages to volts by multiplying the number of millimeters by the setting of the RANGE switch. Record the reading in volts on the data sheet and on the Sanborn charts. Call the average values I_3 and I_4 for Channels 3 and 4, respectively.

4. Obtain the time in seconds for each channel (T_3 and T_4) from the timing marks recorded on the Sanborn chart.

5. Divide I_3 by T_3 to get M_3, and I_4 by T_4 to get M_4.

6. Calculate $|\delta n|$ and θ by the relations:

$$|\delta n| = 2(M_3^2 + M_4^2)^{1/2}$$

$$\tan\theta = M_3/M_4, \quad \theta = \arctan(M_3/M_4)$$

NOTE: In calculating tan θ, be sure to get the correct signs for M_3 and M_4. Tan θ should be negative.

Record the values of $|\delta n|$ and θ.

7. Obtain n_o from the reading of the DC ZERO SUPPRESSION helipot on Channel 2. The worth of the smallest division on the helipot is equal to the setting of the RANGE switch.

8. Check the results by calculating approximate values for $|\delta n|$ and θ as follows:

a) Divide one-half the peak-to-peak voltage of the signal on Channel 2 by the value of n_o. This is $|\delta n|/n_o$.

b) Compare the signals on Channels 1 and 2. Divide the distance which the signal on Channel 2 lags the signal on Channel 1 by the distance required for one complete cycle, then multiply by 360 to get θ in degrees. This will be negative.

Compare these approximate values with the accurate values recorded above. If there is a discrepancy and the reason for it cannot be found, repeat the run.

B. Shim Rod Worth Calculation

1. The value of θ is not needed for calculation of the shim rod worth, but serves as a check on the measurement. At an oscillation frequency of 0.05 cps, it should be about -60°.

2. The calculated amplitude of the transfer function at 0.05 cps is

$$|G(0.05j)| = 1.38.$$

Divide $|\delta n|/n_o$ by this value to get $\delta\rho/\beta$. This is the change in reactivity in dollars caused by moving the shim rod from the midpoint position to the extreme.

3. Add the maximum clockwise displacement of the pointer (Step B-3, Part I) to the maximum counter-clockwise displacement, then divide by 2, which gives the amplitude of the rod motion in degrees. Divide by 9 to get Veeder Units.* The result should be about 40 V.U. Divide the value of $\delta\rho/\beta$ calculated in Step B-2 by the number of Veeder Units, then multiply by 1000. This gives the reactivity worth of shim rod 1 in cents per 10 V.U. Record this value on the data sheet.

4. Find the position of shim rod 1 at its midpoint in O.V.U. by subtracting the reading of the scotch yoke Veeder counter with shim rod 1 at its midpoint position from the reading with shim rod 1 all the way in. Convert this to the position in V.U. by multiplying by four. Record this position.

C. Transfer Function Calculation

1. Subtract the maximum position of shim rod 3 from the minimum position recorded in Step C-1 in Part II. Convert this to reactivity in dollars from the previously measured differential worth curve of shim rod 3 calibrated against the gang. This is the peak-to-peak reactivity worth of the rotor. Divide by 2 to get $\delta\rho/\beta$.

2. Divide $|\delta n|/n_o$ by $\delta\rho/\beta$, which gives the amplitude of $G(j\omega)$. Plot this as a function of frequency of oscillation on a graph similar to Figure V-1. Calculate the exact frequency from the output of P_2 on Sanborn Channel 2. Do not convert the amplitude to decibels (as it is in the figure). On the same graph, plot θ, which is equal to the phase of $G(j\omega)$.

3. Compare the plot with the theoretical curves of $G(j\omega)$ which will be kept with the notebook. If necessary, normalize the measured curve to the theoretical curves at some low-frequency point, and then use this factor to normalize the other points. The high-frequency response will then yield a value of ℓ/β.

*The Veeder Units referred to above correspond to those measured by the Veeder counter on the shim rod drive motors. They are NOT the same as those measured on the Veeder counter on the scotch yoke, which are called O.V.U. (Oscillator Veeder Units). 1 O.V.U. = 4 V.U.

NOTE: In addition to the above graph, plot the measured points on the theoretical curve. Normalize the value measured at 0.05 cps (which is the first point measured) to the theoretical curve, and then use the same normalization factor for the other points.

EXPECTED RESULTS

The calibration of shim rod 1 with the oscillator should agree with the earlier calibration by period measurements. The worth of the rod will be about the same as in the first core.*

The transfer function measurement will yield curves similar to those shown in Figure V-1. The value of ℓ/β obtained from the curves should be about the same as in the first core, where it was 0.075 sec.

EXPECTED CONCLUSIONS

The calibration of shim rod 1 will demonstrate the practicality of high-power shim rod calibrations with the oscillator.

The zero-power transfer function measurement, together with similar measurements at high power, will be used to determine the power coefficient of the SRE.

*AI Staff, "Hazards Summary for Thorium-Uranium Fuel in the SRE," NAA-SR-3175 (Revised).

APPENDIX

A. SCHEDULE

The oscillation of shim rod 1 will begin after the shim rod calibration by period measurements, and will require two days (6 shifts).

The transfer function measurement will follow the axial flux traverses, and will require two days (6 shifts).

B. MANPOWER REQUIREMENTS

The Operations crew and an engineer and an analyst from the Experimental Unit are required for each shift. In addition, C. W. Griffin will be available for advice.

C. EQUIPMENT REQUIREMENTS

1 ionization chamber
1 Keithley micro-microammeter
Electrical equipment shown in Figure V-2
Mechanical equipment shown in Figures V-3, V-6, and V-8
Rotor and stator
Special Zircaloy thimble for rotor and stator
Four Sanborn Channels connected as shown in Figure V-2
Two Sanborn Channels connected to monitor sodium inlet and outlet temperatures

D. CREDIBLE ACCIDENTS

None of the scram circuits will be bypassed during the experiment. During the shim rod oscillation, the interlock which prohibits withdrawal of the safety rods with a shim rod off the lower limit must be bypassed. However, all four of the safety rods will always be out and cocked while the reactor is operating.

The power level will fluctuate only a few percent during the oscillations, since the amplitude of shim motion is only 1/4 inch. At high frequencies, the amplitude of the oscillations will be very small. At low frequencies, the amplitude is larger, but the rate of change of reactivity is very small. Neither case introduces any hazard. In addition, the console operator will always have the ability to drive in shim rods or manually scram the reactor if necessary.

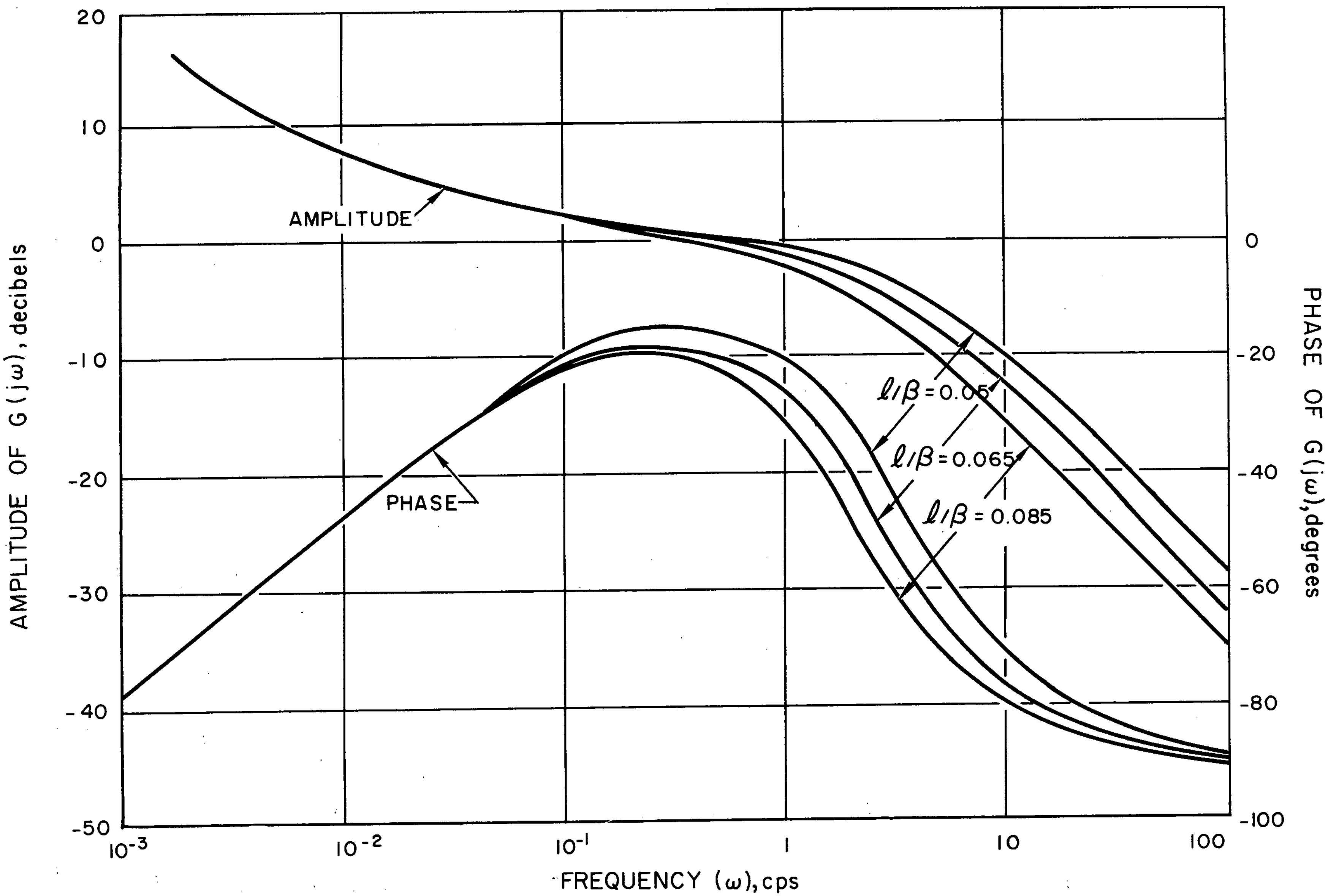


Figure V-1. Transfer Function, G(jω), for Different Values of ℓ/β

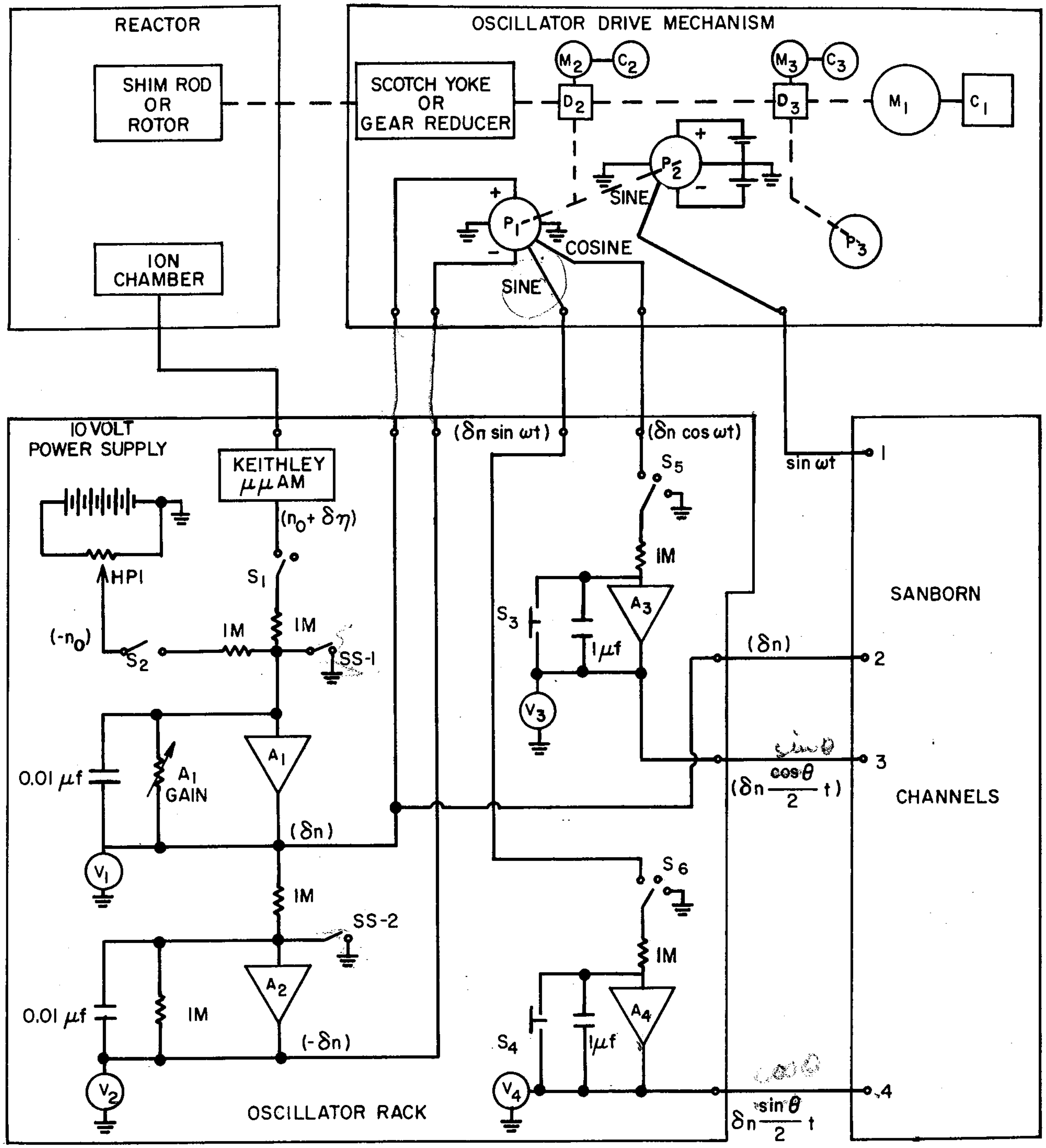


Figure V-2. Reactor Oscillator Circuit Diagram

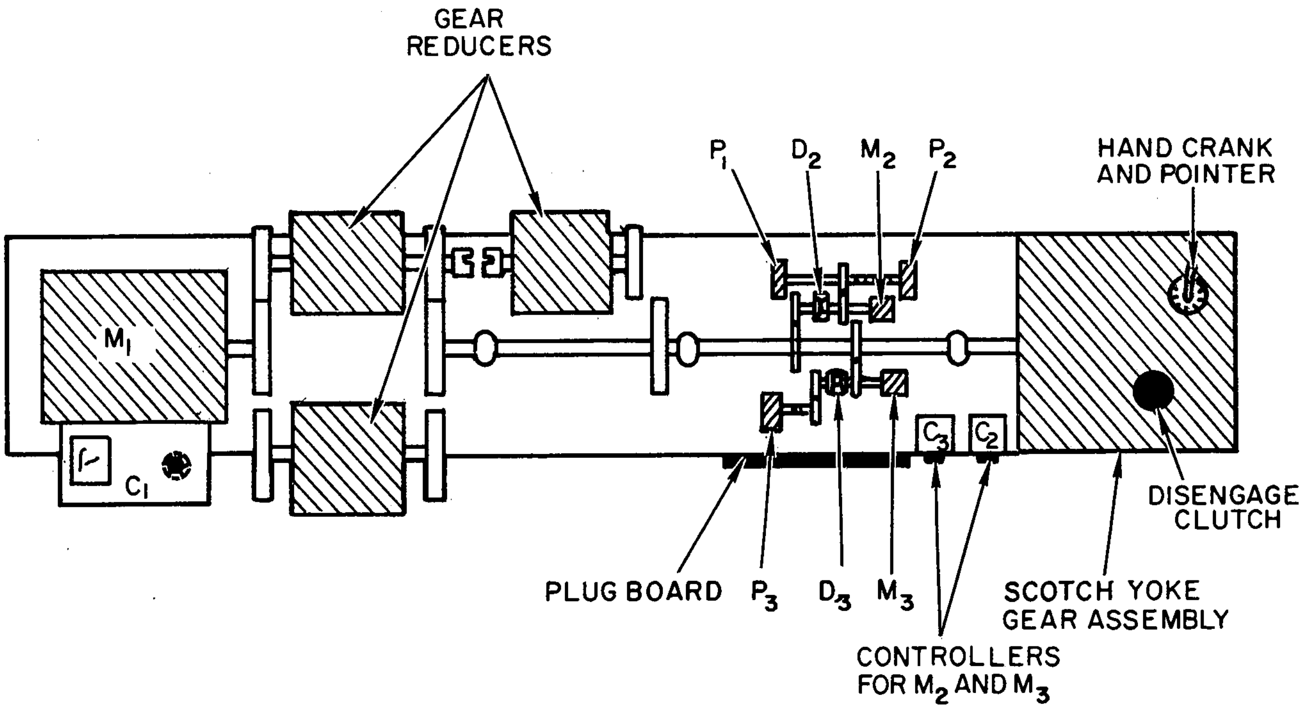


Figure V-3. Layout of Oscillator Driving Mechanism

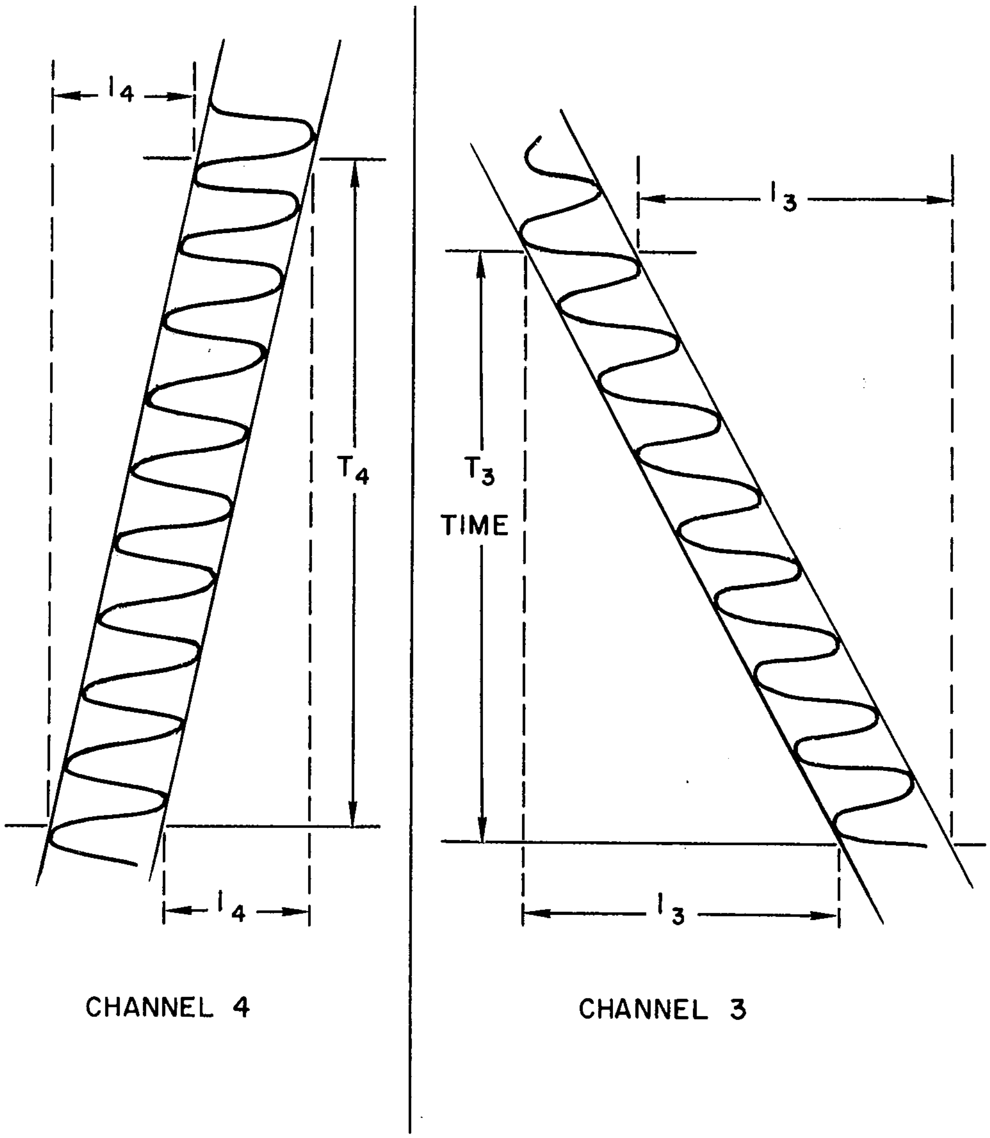


Figure V-4. Output of Sanborn Recorder

Run No.		0	1	2
1. Veeder Counter on Shim Rod 1 Drive, V.U.				
Veeder Counter below loading face, V.U.				
2. Readings on Scotch Yoke which correspond to 1.	Veeder Counter			
	Pointer			
3. Pointer Positions (in degrees)	Maximum Clockwise Displacement			Same as Run 1
	Maximum Counter-Clockwise Displacement			Same as Run 1
	Midpoint Position			Same as Run 1
4. Veeder Counter Reading with Pointer on Midpoint Position (O.V.U.)				
5. Sodium Inlet Temperature (°F)				
Sodium Exit Temperature (°F)				
Primary Flow (gpm)				
6. Log N reading (before oscillation)				
7. Shim Rod Positions before Oscillation Begins, (V.U.)	Shim Rod 2			
	Shim Rod 3			
	Shim Rod 4			
8. Reading of V_1 (volts)				
Reading of V_2 (volts)				
9. Log N average reading (during oscillation)				
10. Keithley average reading (during oscillation)				
11. Position of Shim Rod 3 (during oscillation)				
12. Attenuator Range setting On Sanborn Channels	Channel 1			
	Channel 2			
	Channel 3			
	Channel 4			
13. Helipot reading on Channel 2				
14. Helipot Reading in volts ($= n_o$)				

Figure V-5. Data Sheet for Calibration of Shim Rod 1 with the Reactor Oscillator (Sheet 1 of 2)

ANALYSIS OF ROD OSCILLATION MEASUREMENTS

Run No.		1	2
Value of I_3	from top line, cm		
	from bottom line, cm		
	average, cm		
	average, volts $(=I_3)$		
Value of I_4	from top line, cm		
	from bottom line, cm		
	average, cm		
	average, volts $(=I_4)$		
Time interval on channel 3 $(=T_3)$, sec.			
Time interval on channel 4 $(=T_4)$, sec.			
$M_3 = I_3/T_3$			
$M_4 = I_4/T_4$			
$\lvert\delta n\rvert = 2(M_3^2 + M_4^2)^{1/2}$			
$\tan\theta = M_3/M_4$			
$\theta = \arctan(M_3/M_4)$			
$\lvert\delta n\rvert/n_o$			
Approximate Values	$\lvert\delta n\rvert/n_o$		
	θ		
$(\lvert\delta n\rvert/n_o)/1.38 = \delta\rho/\beta$ (dollars)			
Amplitude of Motion of Shim Rod 1	in degrees		
	in V.U.		
Worth of Shim Rod 1, cents/10 V. U.			
Worth of Shim Rod 1 from Period Measurements, cents/10 V.U.			

Figure V-5. Data Sheet for Calibration of Shim Rod 1 with the Reactor Oscillator (Sheet 2 of 2)

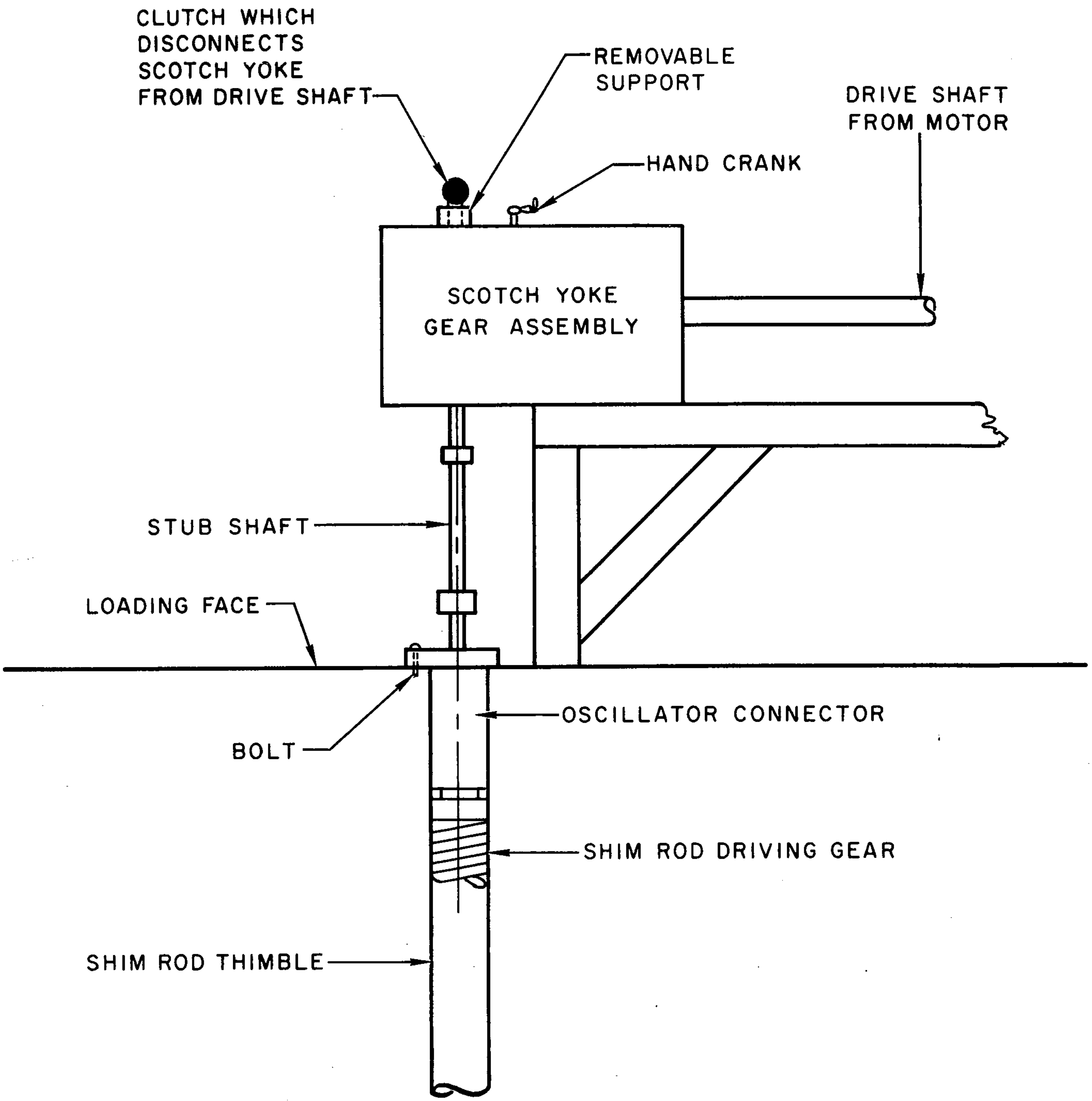


Figure V-6. Connection of Oscillator to Shim Rod

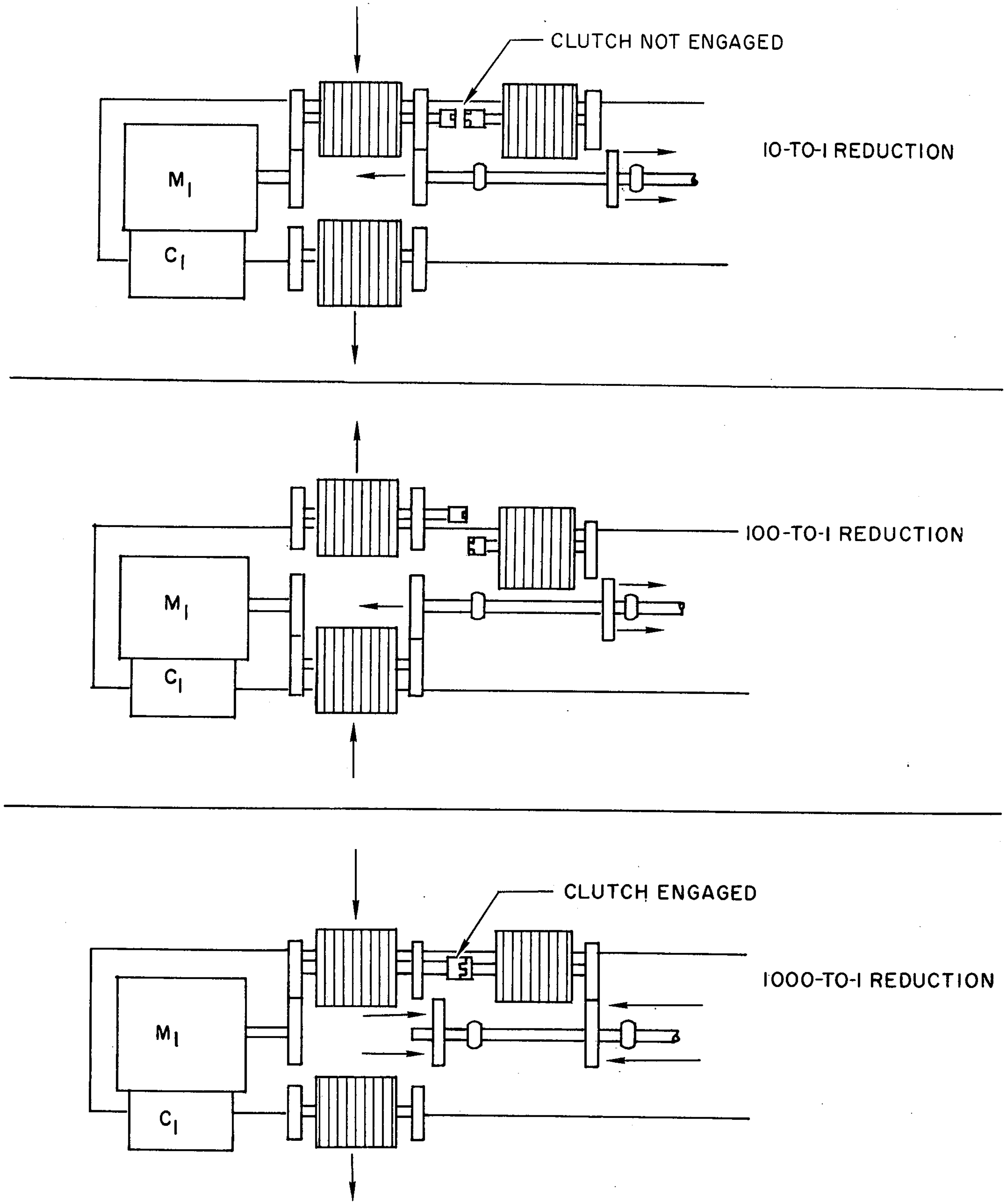


Figure V-7. Settings for Necessary Gear Reductions

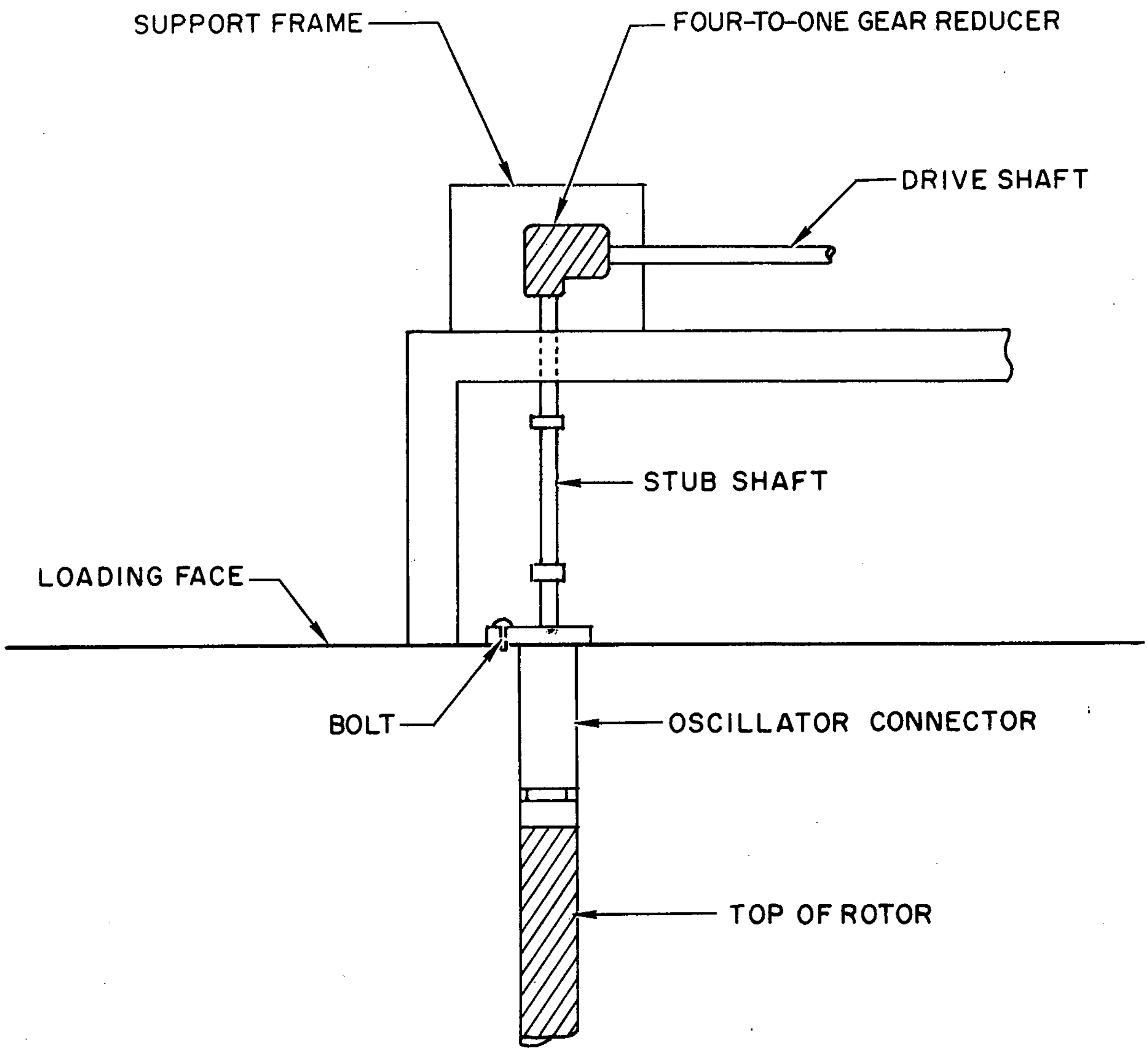


Figure V-8. Connection of Oscillator to Rotor

Run No.		0	1	2	3	4
1. Positions of Shim Rod 3	Maximum					
	Minimum					
	Midpoint					
2. Frequency of Oscillation, cps						
3. V_1 reading, volts						
V_2 reading, volts						
4. Range Switch Settings on Sanborn Channels		1				
		2				
		3				
		4				
5. Sodium Temperatures, °F	Inlet					
	Outlet					
	Average					
6. Helipot Reading on Channel 2						
Helipot Reading in Volts						
Analysis of Measurements						
Value of I_3	from top line, cm					
	from bottom line, cm					
	average, cm					
	average, volts					
Value of I_4	from top line, cm					
	from bottom line, cm					
	average, cm					
	average, volts					
T_3, sec.						
T_4, sec.						
$M_3 = I_3/T_3$						
$M_4 = I_4/T_4$						
$\lvert\delta n\rvert = 2(M_3^2 + M_4^2)^{1/2}$						
$\tan\theta = M_3/M_4$						
$\theta = \arctan(M_3/M_4)$						
$\lvert\delta n\rvert / n_o$						
Approx. Values	$\lvert\delta n\rvert / n_o$					
	θ					
Peak-to-Peak Reactivity Worth of Rotor, Cents						
$\delta\rho/\beta$, Cents						
$G(j\omega) = (\lvert\delta n\rvert/n_o)/(\delta\rho/\beta)$						

Figure V-9. Data Sheet for Zero Power Transfer Function Measurement

VI

RADIAL STATISTICAL WEIGHT

By

R. A. MOSER

CONTENTS

FIGURES

TABLES

OBJECTIVE

The objective of this experiment is to measure the difference in reactivity produced by replacing a five-rod, 7.1 wt % U^{235}, thorium-uranium fuel cluster with a five-rod enriched-uranium fuel cluster, with a dummy assembly, and with sodium, at various positions in the core with an operational fuel loading.

PURPOSE

The difference in reactivity measured when a thorium-uranium fuel cluster is replaced with a dummy assembly* is proportional to the radial statistical weight, i.e., proportional to the product of the flux and adjoint flux for a specific channel. The ratio of appropriate statistical weights permits estimation of reactivity changes caused by moving in-core components from one channel to another.

The determination of radial statistical weight is necessary for accurate interpretation of fuel worth, long-term reactivity changes, and other reactivity measurement data.

The accuracy of comparative worth measurements using calibrated shim rods is heavily dependent on the equality of flux levels at the shim rods during any series of measurements. Flux perturbations produced in worth measurements of fuel with respect to fuel are less than those produced in fuel-dummy measurements. A measurement of the difference in reactivity produced when a five-rod thorium-uranium fuel cluster is replaced with a five-rod enriched-uranium fuel cluster, will provide data necessary to evaluate the validity of the experimental technique and conclusions associated with this experiment.

Data relative to the loss in reactivity produced when fuel is replaced with sodium will be used to investigate methods of flattening the flux of the operational

*A dummy assembly consists of a graphite-filled, zirconium can attached to standard fuel-support hardware in place of fuel. Insertion of the dummy in place of fuel within a particular reactor channel essentially eliminates the sodium ordinarily in a fuel-filled channel.

thorium-uranium core. Further, a measurement of sodium to fuel worth may permit calculation of the total worth of in-core sodium.

METHOD

With the reactor in an isothermal condition at 340°F, the shim rods will be withdrawn the requisite amount to permit steadying the reactor at some constant low-power flux level "B." The shim configuration will be recorded. The reactor will be shut down to permit replacement of a thorium-uranium fuel cluster with a dummy assembly. Reactor flux will again be increased to "B" and steadied. The shim-rod configuration will be recorded. In certain channels, the thorium-uranium fuel will be replaced first with a dummy assembly, then with enriched-uranium fuel, and finally with sodium alone. The shim-rod configurations required to hold power steady at "B" will be recorded after each replacement.

The difference in total excess reactivity of the core produced by replacing fuel with a dummy assembly, with enriched-uranium fuel, and with sodium can be calculated by integrating the differential worth of shim rod 3 between the two positions of shim rod 3 in the critical configurations. Shim rods 1, 2, and 4 will have been withdrawn to the same position for both shim rod configuration measurements.

Should the reactor temperature drift during the experiment, the isothermal temperature coefficient will be integrated between the appropriate limits to permit correction of the measured reactivity difference.

PROCEDURE

1a. (O) Maintain the core in an isothermal condition at 340°F as indicated by the average of the main primary (reactor) inlet and outlet sodium temperatures. This temperature, to be held constant throughout the experiment, will be maintained by using process line heaters and, if necessary, pool heaters. Maintain a flow rate of 1000 gpm in the main primary sodium loop. This flow rate must be held constant throughout the experiment. There must be no coolant flow in the auxiliary primary loop.

1b. (E) Position the thermopile (see Figure VI-1) in R-50 at the midplane index mark. Tape the thermopile leads to the reactor loading face.

2. (O) Withdraw shim rod 3 to 10 inches out.

3. (O) Individually withdraw shim rods 1, 2, and 4 to the same distance above their lower limit switches such that the reactor is critical at "B." A power level for point "B" will have been established in Experiment III. DO NOT move shim rods 1, 2, and 4 once this positioning step has been completed.

4. (O) Steady reactor power at "B" for 20 minutes by adjusting shim rod 3 only.

5. (E) After power has been steady at point "B" for 20 minutes, record the core temperatures, i.e., the average of the reactor inlet and outlet temperatures as recorded on the Sanborn and the Veeder readings for all four shim rods, on the data sheet shown in Figure VI-2. Record the value of the thermopile signal.* Record the log N reading corresponding to point "B." (Use this log N value in making future adjustments of reactor power to "B.")

6. (O) Shut the reactor down.

7. (E) Record the Veeder readings on each of four shim-rod drives immediately prior to their removal from the reactor loading face.

8. (O,E) Remove the TV equipment and safety- and shim-rod drives from the reactor loading face. Care should be taken to prevent turning the shim-rod drive shafts during or after this removal operation. <u>Veeder counter attachment and shim-rod lower limit positions should not be altered without prior notification of the Experimental Unit Engineer.</u>

9. (E) Record the Veeder readings in shim-rod thimbles 1 and 2.

10. (O) Replace the fuel in the first fuel channel listed in Table VI-1 and shown in Figure VI-3 with the Standard dummy assembly.

11. (O,E) Prepare to replace the shim-rod drives. Just prior to replacing the shim-rod drives, check to make certain that the Veeder readings on

*Data relative to the operational characteristics of the thermopile are being collected to permit evaluation of the feasibility of incorporating the thermopile in future reactor physics experiments.

each shim rod drive as well as those in thimbles 1 and 2 have not been altered. Replace the shim-rod and safety-rod drives, TV equipment, etc.

TABLE VI-1

CORE CHANNELS TO BE USED IN THIS EXPERIMENT

Channel Number	Ring Number
R-44	0
R-55	1
R-54	2
R-42	3
R-53	4
R-41	5

12. (E) Check the position of the thermopile in R-50 which provides the input signal for the Sanborn Recorder. If the detector has been moved from its indexed position, reposition the detector.

13. (O) Withdraw shim rods 1, 2, and 4 to the configuration established for these shim rods in Step 3. Repeat Steps 4 through 7.

14. (O, E) ~~Repeat Steps 4 through 9.~~ Exchange the dummy assembly for fuel in the channel in which measurements were just completed.

15. (O,E) Repeat Steps 10 through 14 for each of the remaining fuel channels listed in Table VI-1.

16. (O) Replace the dummy assembly in the channel last used in Step 15 with thorium-uranium fuel. Replace the thorium-uranium fuel in R-53 with the five-rod Standard enriched-uranium fuel cluster.

17. (O, E) Repeat Steps 11 through 14.

18. (O) Replace the enriched-uranium fuel cluster with the thorium-uranium fuel originally in R-53.

19. (O) Replace the thorium-uranium fuel in R-55 with the Standard enriched-uranium fuel cluster.

20. (O, E) Repeat Steps 11 through 14.

21. (O) Remove the Standard enriched-uranium fuel from R-55.

22. (O, E) Repeal Steps 11 through 14 in order to measure the worth of sodium in R-55.

23. (O) Re-insert the thorium-uranium fuel cluster originally positioned in R-55.

24. (O, E) Replace the shim rod drives. Repeat Steps 11 through 14.

25. (E) Remove the thermopile from R-50 and R-60 and place them in the thermopile shield cask.

26. Proceed to the next experiment.

ANALYSIS

I. NOMENCLATURE

ρ_{x_o}* = reactivity absorbed by shim rod 3 with reactor power steady at point "B," and with an operational loading of fuel in the reactor; i.e., the position of shim rod 3 recorded in Step 5.

ρ_x = reactivity absorbed by shim rod 3 where either the Standard dummy assembly, the Standard enriched-uranium fuel cluster, or sodium, has replaced the thorium-uranium fuel.

T_o and T_i = reactor temperatures (average of the main primary reactor inlet and outlet temperature) existent during the measurements.

$\Delta\rho$ = difference in reactivity absorbed by shim rod 3.

ρ_I = integrated isothermal temperature coefficient of reactivity between temperatures T_o and T_i, i.e.,

$$\rho_I = \overline{\frac{d\rho}{dt}}(T_i - T_o),$$

where

$\overline{\frac{d\rho}{dt}}$ = change in reactivity resulting from temperature changes between T_o and T_i,

*"x" is the distance measured from the lower limit switch to the tip of the shim rod.

T_o = core temperature with thorium-uranium fuel,

T_i = core temperature with dummy assembly, enriched-uranium fuel, or sodium,

ρ_d = difference in reactivity between thorium-uranium fuel and dummy assembly, enriched-uranium fuel, or sodium.

II. PROCEDURE

Analysis of the radial statistical weight data, including the development of the graph described in Step (e) below, but excluding the isothermal temperature coefficient correction, will be performed as the experiment progresses. These preliminary results will provide a means of evaluating the consistency of the data.

a) Determine ρ_{x_o} and ρ_{x_i}, using the integral shim rod worth curve for shim rod 3, where shim rod 3 has been calibrated against the gang of shim rods 1, 2, and 4 during Experiment IV. This curve will be obtained from a shim rod calibration experiment to be performed prior to this experiment.

b) Calculate $\Delta\rho$, where

$$\Delta\rho = \rho_{x_o} - \rho_{x_i} .$$

c) Calculate ρ_I, using the isothermal temperature coefficient of reactivity curve. This curve will be developed from data collected in Experiment X.

d) Calculate ρ_d, where

$$\rho_d = \Delta\rho + \rho_I .$$

e) Plot ρ_d as a function of radial displacement from the core axis.

EXPECTED RESULTS

The estimated worth of thorium-uranium fuel with respect to a dummy assembly, as a function of radial displacement from the core axis, has been calculated (see Table VI-2). These calculations are based on fuel worth and radial statistical weight measurements made with the first SRE fuel loading,[*,†] and on the worths of five-rod thorium-uranium, and seven-rod enriched-uranium fuel clusters, measured in the SGR Critical Facility.[§]

TABLE VI-2

ESTIMATED WORTH OF Th-U FUEL WITH RESPECT TO A DUMMY ASSEMBLY AS A FUNCTION OF RADIAL DISPLACEMENT FROM CORE AXIS

Ring Number	Expected Fuel Worth With Respect to a Dummy Assembly (dollars)
0	1.9
1	1.2
2	1.1
3	1.0
4	0.8
5	0.6

*R. W. Campbell and R. W. Woodruff, "Reactivity of Thorium-Uranium Fuel," TDR-2826, May 3, 1958

†R. W. Woodruff, "Radial Statistical Weight for the SRE," TDR-3934, May 27, 1959

§R. W. Keaton (unpublished data)

APPENDIX

A. SCHEDULE

The reactor will have been loaded in accordance with Figure VI-4 in preparation for this experiment. The six channels in which measurements are to be made are listed in Table VI-1 and shown in Figure VI-3. The estimated time lapse between configurations with fuel and dummy assembly is 12 hours. The estimated time required to complete the experiment, i.e., from the initial loading through the completion of measurements in R-55, is six days.

B. MANPOWER REQUIREMENTS

The Experimental Unit will supply one engineer and one assistant per shift to conduct the experiment, i.e., operate the counters, calculate reactivity differences, etc.

The Operations Unit will provide the normal working crew to make fuel changes and operate the reactor.

C. EQUIPMENT REQUIREMENTS

1	Standard dummy assembly
1	Standard five-rod enriched-uranium fuel cluster
1	Nuclear Chicago neutron-sensitive thermopile
1	Neutron source
1	Four-channel Sanborn Recorder

D. CREDIBLE ACCIDENTS

In every case, the measurements required will be performed after some quantity of excess reactivity has been removed from the core, e.g., fuel replaced with dummy assembly, etc. Except for the changes in fuel loading associated with the performance of the experiment, the reactor will be operated under standard low-power conditions.

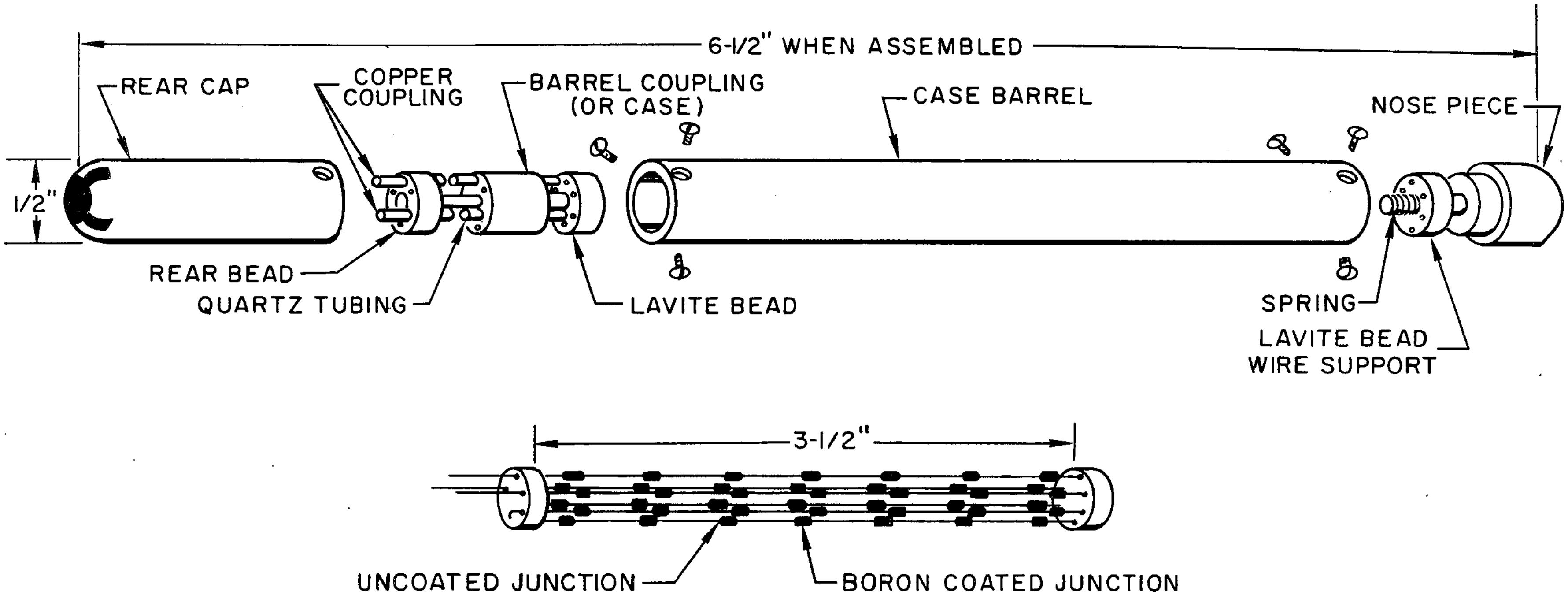
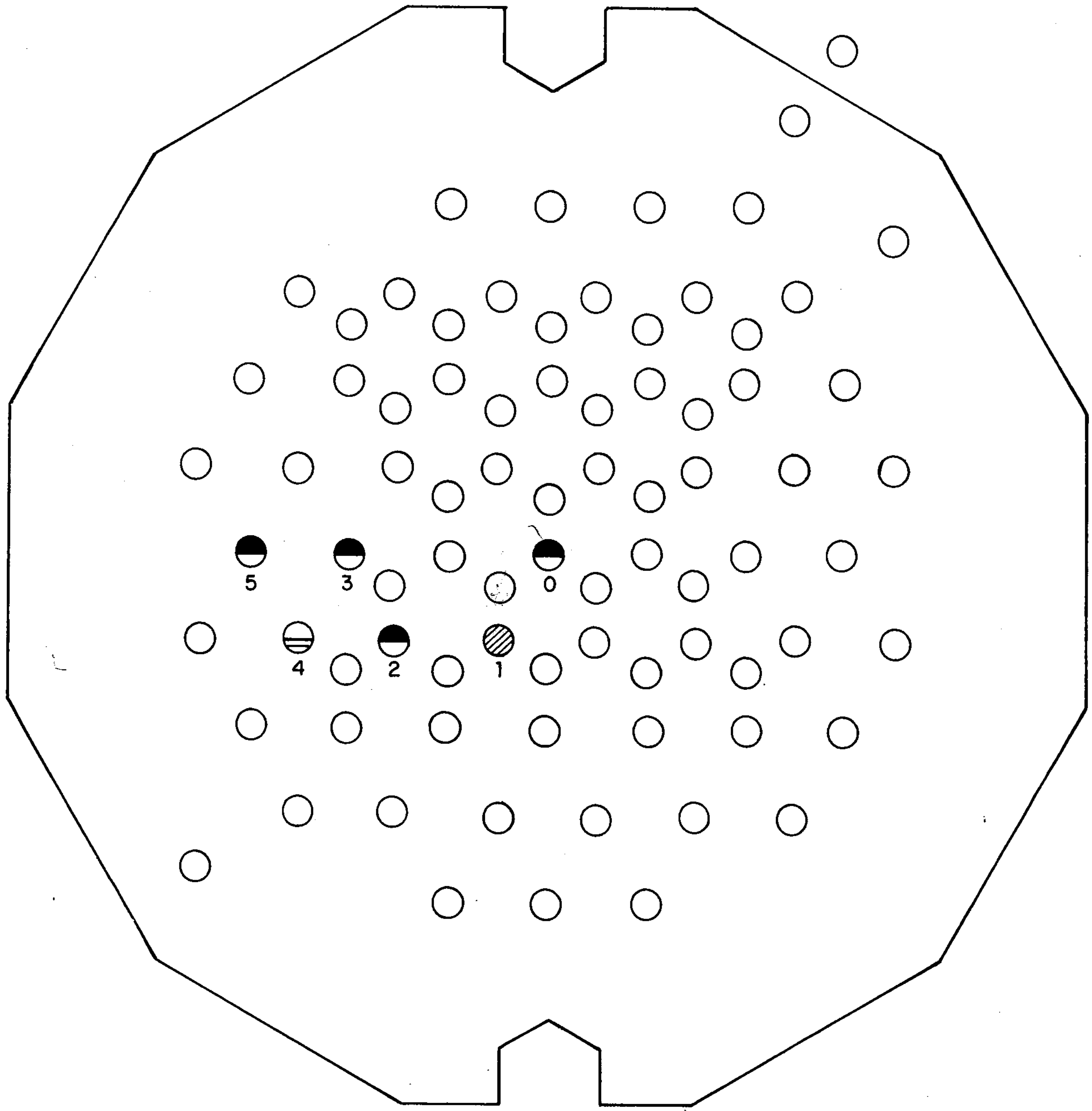


Figure VI-1. Neutron-Sensitive Thermopile

Data		Operational Fuel Load	R-44	R-55	R-54	R-42	R-53	R-41	R-53	R-55	R-55
			Dummy						Enriched Uranium		Sodium
Shim Rod Positions, V.U.	1										
	2										
	3										
	4										
Reactor Inlet Temperature, °F											
Reactor Outlet Temperature, °F											
Average Reactor Temperature, °F											
Log N Recorder % of fuel power											
Thermopile Signal, mv											
$T_i - T_o$, °F											
ρ_x, dollars											
$\Delta\rho$, dollars											
ρ_I, dollars											
ρ_d, dollars											

Figure VI-2. Reactivity Data Form



FUEL WORTH WITH RESPECT TO DUMMY MEASUREMENT CHANNELS

FUEL WORTH WITH RESPECT TO DUMMY & ENRICHED-URANIUM FUEL MEASUREMENT CHANNELS

FUEL WORTH WITH RESPECT TO DUMMY, ENRICHED-URANIUM & SODIUM MEASUREMENT CHANNELS

NUMERALS INDICATE RING NUMBERS

Figure VI-3. Positions of Measurement Channels

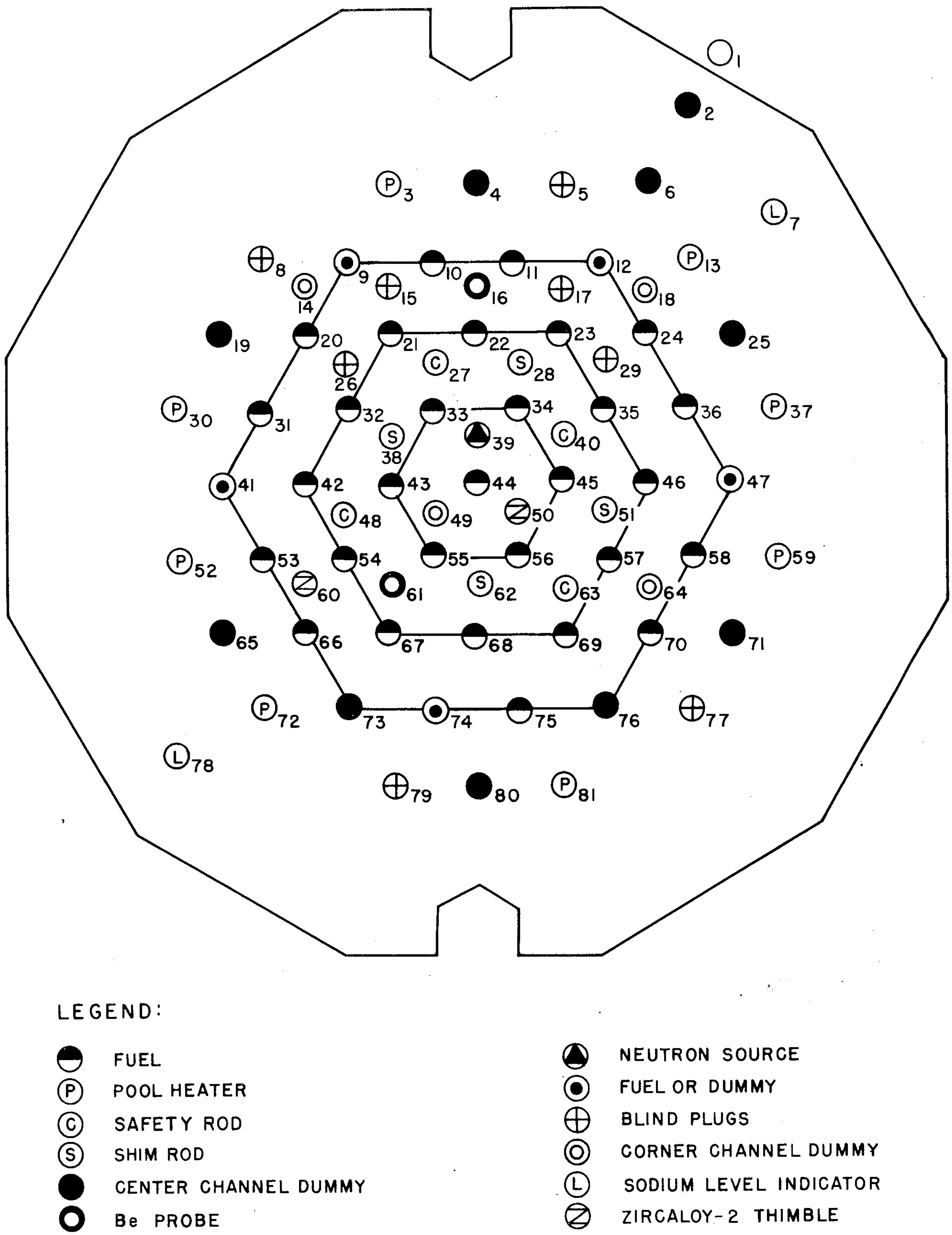


Figure VI-4. Core Loading for Experiment

VII

THERMAL NEUTRON FLUX MEASUREMENTS

By
R. A. MOSER

CONTENTS

FIGURES

OBJECTIVE

The objective of this experiment is to determine the low-power axial flux distribution in an SRE thorium-uranium core with an operational fuel loading.

PURPOSE

A measurement of axial flux is required for reactor analysis.

METHOD

With the reactor in an essentially isothermal condition at 340°F, and with reactor power steady at some low-power flux "P," (i.e., 0.2 of one decade below point "C"), a stainless-steel wire with cadmium sleeves attached at 4-inch intervals along its length will be inserted into a special Zircaloy-2 thimble positioned near the center of the core. The position of a calibrated shim rod will be adjusted to hold reactor power steady at "P" as the stainless-steel wire with cadmium sleeves is inserted into the reactor. The worth of the cadmium on the stainless-steel wire will be measured as a safety consideration. Since each of the flux-measuring wires to be irradiated in this experiment will have cadmium sleeves affixed along its length, the withdrawal of the flux-measuring wires will constitute an addition of reactivity to the core. Failure to adjust the position of the shim rods during the withdrawal of the irradiated wires will result in an increase in reactor power.

The cadmium sleeve spacing will vary from wire to wire, e.g., 6-inch spacing on one wire, 8-inch spacing on another, etc. Cadmium spacing is being varied to ensure that the flux depression produced by the cadmium sleeving will not perturb the thermal flux along the entire length of the unshielded segments of the flux-measuring wire.

With reactor power steady at "P," the flux-measuring wires will be inserted into the special Zircaloy-2 thimbles and exposed the requisite time to sufficiently activate the wires such that standard counting techniques can be employed to determine values of relative thermal flux. The measured thermal flux will be plotted as a function of axial position in the core.

Following the exposure of the flux measuring wires and their subsequent removal from the reactor, a neutron-sensitive thermopile will be lowered into one of the Zircaloy-2 thimbles. With reactor power again steady at "P," the thermopile will be lowered into the thimble in 6-inch increments until the upper reflector and the core have been traversed. If necessary, shim rod adjustments will be made to hold reactor power steady at "P."

After each incremental movement of the thermopile, its output signal will be recorded. The signal will be plotted as a function of the position of the thermopile along the core axis. The thermopile output signal will be related to flux, using the results of the irradiated wire analysis.

PROCEDURE

Both gold and cobalt wires will be used in this experiment to measure the axial flux distribution in the core. Nine wire support tubes (see Figure VII-1) will be fabricated to contain the wires during their exposure in the reactor. Six of the support tubes will be loaded with gold wire in the manner shown in Figure VII-1. Two tubes will be loaded with cobalt wire, and one tube will contain stainless-steel wire. Construction of the support tubes, suspension assemblies, and positioning caps (see Figure VII-2), as well as the loading of the tubes, will be performed by the Radiation Measurements Unit.*

The loaded support tubes and attached assemblies will be positioned near the reactor loading face prior to the initiation of Step 3 in this procedure.

1. (O) Maintain the core in an isothermal condition at 340°F. Line heaters and, if necessary, pool heaters are to be used to control reactor temperature.

2. (O) Maintain a constant flow rate of 1000 gpm in the main primary sodium loop. There will be no flow in the auxiliary primary coolant loop.

3. (O) Withdraw the safety rods to their upper limits.

---

*R. A. Moser and S. F. Burton, "Absolute and Relative Axial Thermal Flux Measurements in an SRE Thorium-Uranium Core" (TWR 5056 to Radiation Measurements Unit, May 1960).

4. (O) Withdraw shim rod 3 to 36 inches.

5. (O) Individually withdraw shim rods 1, 2, and 4 to the same distance from their lower limit switches such that the reactor is critical. Adjust reactor power to point "P" using shim rod 3 only. DO NOT move shim rods 1, 2, and 4 during the remainder of this experiment.

6. (O) Hold reactor power steady at "P" during Steps 7 through 10.

7. (E) Prepare to insert the wire support tube containing stainless steel wire into the Zircaloy-2 thimble in R-50. The presence of both the Experimental Unit engineer and assistant on the reactor loading face will be required during Steps 8 through 18.

8. (E) Position the support tube and attached assemblies near reactor channel R-50.

9. (E,H) Remove the special shield plugs from the Zircaloy-2 thimble in R-50 (see Figure VII-3). Health Physics monitoring services will be required in this step. Both fast- and slow-neutron and gamma surveys should be performed over the unshielded thimble. The measured values of neutron and gamma intensities will be recorded in the Experimental Unit Laboratory notebooks.

10. (E) After the shield plug has been removed from the Zircaloy thimble, thread the support tube suspension cable up through the shield cable channel in the manner shown in Figure VII-2. Attach the tube positioning cap to the suspension cable at the RED cable index mark.

11. (O,E) Ascertain that reactor power is steady at "P." If adjustment of shim rod 3 is required to hold power at "P," wait 10 minutes before proceeding to the next step.

12. (E) When reactor power has been steady at "P" for 10 minutes after the last adjustment of shim rod 3, record the reactor inlet and outlet coolant temperatures as shown on the Sanborn Recorders, the positions of all four shim rods, and the log N recorder reading, on the axial flux data form (see Figure VII-4).

13. (E) Prepare to insert the wire support tube into R-50. Make certain that the suspension cable attached to the tube will not become entangled during the insertion of the support tube.

14.(E) Carefully insert the support tube into the thimble guide tube in channel R-50. Lower the support tube until its upper end is level with the top of the thimble guide tube. Stop insertion of the support tube.

15.(E) While holding the support tube suspension cable, carefully re-insert the two-region shield plug into the Zircaloy thimble in R-50. When the plug is in place, pull the support tube up snugly against the under side of the shield plug by pulling on the suspension cable.

16.(E) Re-read through Steps 16 before proceeding with the tube insertion. At a given signal, begin full insertion of the support tube. By holding firmly to the positioning cap and letting the suspension cable slip through the hands, the support tube will slide down the guide tube to its lower limit. The lower limit will have been reached when the position cap is flat against the lead shield plug support plate (see Figure VII-2). The insertion rate must be such that between 15 to 20 seconds is required to insert the support tube to its lower limit.

17.(O) As soon as the support tube insertion begins, adjustments in the position of shim rod 3 will be made to permit holding reactor power steady at "P."

18.(E) After reactor power has been steady at "P" for 10 minutes following the last adjustment of shim rod 3, record the position of shim rod 3 on the data form.

19.(E,H) Prepare the loading face for the support-tube withdrawal operation. Because of the possible activation of the support tube suspension cable, cable lubricants, etc., it will be necessary to prepare a small area around the special measurement thimbles to receive the suspension cables as they are withdrawn from the reactor. This will be accomplished by spreading a sheet of plastic film over the areas involved. Further, a 5-gallon pasteboard carton should be obtained to receive the cable as it is removed from the reactor. Shoe covers, lab coat, and cotton gloves will be worn by the person actually withdrawing the wire support tube from the reactor. Health Physics monitoring services will be required during the actual removal operation to measure levels of induced activity.

20.(E) Start the withdrawal of the support tube from its lower limit. Continue withdrawal of the tube until the upper end of the tube reaches the underside of the thimble shield plug. The withdrawal rate must be such that 15 to 20 seconds is required to raise the tube to its upper limit.

21.(O) The position of shim rod 3 will be adjusted during the tube withdrawal to hold reactor power steady at "P."

22.(E) Remove the support tube from R-50 and place it in an empty fuel storage cell. Health Physics monitoring services will be required in this step.

23.(O) Hold reactor power steady at "P" during Steps 24 through 28.

24.(E) Prepare to insert the first set of wire support tubes into the Zircaloy-2 thimbles in R-60 and R-50. The presence of both the Experimental Unit engineer and assistant on the reactor loading face will be required during Steps 27 through 29.

25.(E) Select the two appropriate support tubes from those positioned near the reactor loading face. The support tubes containing cobalt wire should be selected in this step.

26.(E) Position the support tubes and attached assemblies near reactor channels R-50 and R-60.

27.(E,H) Repeat Step 9.

28.(E) Repeat Step 10.

29.(E,O) Repeat Steps 11 through 17 in R-50, using a support tube loaded with cobalt wire.

30.(E) As soon as the support tube is fully inserted into the reactor, record the insertion time, i.e., the clock time as indicated by the reactor high-bay clock read in hours, minutes, and seconds, on the axial flux data form.

31.(E) Record the position of shim rod 3 on the data form.

32.(E) Repeat Step 19. Preparation of the removal area on the reactor loading face will have been completed well in advance of the removal of the support tube.

The Experimental Unit engineer and assistant and the Health Physicist should be positioned on the loading face, ready to remove the first wire support tube several minutes before the reactor high-bay clock indicates the removal time.

> <u>NOTE</u>: The exposure time for each wire, i.e., the time the support tube will remain at its lower insertion limit, will be based on calculations to be performed by the Radiation Measurements Unit prior to the start of this experiment. Preliminary calculations indicate that each cobalt wire will have an exposure time approximating 4 hours. Exposure time for each gold wire will be on the order of 30 minutes. The calculated exposure times will take into consideration the positions of the two Zircaloy-2 measurement thimbles in the core. Exposure times as a function of wire type and core position will be provided by the Experimental Unit at the start of this experiment.

33. (E) Prepare to withdraw the support tube from the reactor.

34. (E) At a given signal indicating the attainment of the removal time, start the withdrawal of the support tube from its lower limit. Continue withdrawal of the tube until the upper end of the tube reaches the underside of the thimble shield plug. Withdrawal will be completed in approximately 20 seconds.

35. (E) Record the time, on the axial data form, as indicated by the high-bay clock, read in hours, minutes, and seconds at which the tube withdrawal was completed.

36. (O) Compensate as necessary for the withdrawal of the support tube from the reactor by inserting shim rod 3 to hold reactor power steady at "P." When no further movement of shim rod 3 is required to hold power steady at "P," record the position of shim rod 3 on the axial flux data form.

37. (E) Transfer the irradiated wire from the support tube to the shielded transport cask shown in Figure VII-5. The transfer procedure, prepared by the Radiation Measurements unit, will be attached to the shield cask at the start of the experiment.

38. (E) Repeat Step 22 using the same storage cell. Health Physics monitoring services will be required in this step.

39. (E,O) Repeat Steps 26 through 38 in R-60, using a support tube loaded with cobalt wire.

40. (E,O) Repeat Steps 26 through 38 in R-50, and then in R-60, using support tubes loaded with gold wire. The wire used in this step will have 4 inch cadmium spacing.

> NOTE: When the gold wires are irradiated, it will be necessary to measure the total exposure times with a stop watch. Start the stop watch when the BLACK suspension cable mark (see Figure VII-2) goes into the reactor during the tube insertion operation. Stop the watch when the marker is exposed during the withdrawal operation. Record the wire exposure time as measured with the stop watch, along with the insertion and removal time as indicated by the reactor high-bay clock, on the axial flux data form.

41. (E,O) Repeat Steps 26 through 38 in R-50 for each of the four remaining support tubes containing gold wire. The wire in these tubes will have 6-, 8-, 10-, and 12-inch cadmium spacings, respectively.

42. (E) With the two-region shield plug removed from the Zircaloy-2 thimble in R-60, thread the leads from a neutron thermopile (see Figure VII-2 and VII-6) through the shield plug. Connect the thermopile leads to the Leeds and Northrup potentiometer.

43. (E) Zero and balance the potentiometer according to the instructions attached to the instrument.

44. (O) Hold reactor power steady at "P" by adjusting the position of shim rod 3.

45. (E) After power has been steady at "P" for 10 minutes, repeat Step 12.

46.(E) Lower the thermopile 6 inches into the guide tube in R-60. Replace the thimble shield plug in R-60 as in Step 15.

47.(O) Repeat Step 44.

48.(E) Wait 5 minutes after either an adjustment of shim rod 3 or an incremental movement of the thermopile before taking the data required in Step 49.

49.(E) After the 5-minute waiting period, record the thermopile output signal as indicated on the Leeds and Northrup potentiometer, the reactor inlet and outlet coolant temperatures as recorded on the Sanborn Recorders, the position of shim rod 3, and the log N recorder reading, on the axial flux data form.

50.(E) Lower the thermopile to the next cable marker, i.e. to the top of the upper reflector.

51.(O) If necessary, repeat Step 44.

52.(E) Repeat Step 49.

53.(E,O) Repeat Steps 50, 51, and 52 until the thermopile has traversed the upper reflector and core.

54.(E) Withdraw the thermopile to the position established in Step 50.

55.(O,E) If necessary, repeat Step 44.

56.(E) Repeat Step 49. Prepare to withdraw the thermopile from R-60. As was the case during the withdrawal of the wire support tubes, an area will be prepared on the reactor loading face to receive the thermopile and attached leads. Protective clothing requirements and Health Physics monitoring services are the same in this step as those listed in Step 19.

57.(E) Withdraw the thermopile from R-60 to its upper limits, i.e. the underside of the shield plug. Tape the thermopile leads to the reactor loading face shield.

58.(E) Repeat Steps 42 through 57 for R-50.

59.(E) Scram the reactor. Remove the thermopiles from R-60 and R-50 and place them in the thermopile shield cask (see Figure VII-7).

60.(E) Replace the special shield plugs in the thimbles in R-60 and R-50.

61.(O,E) Proceed to the next experiment.

EXPECTED RESULTS

Analysis of the irradiated wires will provide an experimental measurement of the axial thermal flux distribution between the top of the upper reflector and the lower core-reflector interface in reactor channels R-50 and R-60. Comparison of the calculated and measured values of relative flux will permit evaluation of the calculative techniques used to estimate flux distribution in the SRE.

Further, the comparison of the axial flux distribution measured using gold, cobalt, and boron (the thermopile) should provide:

a) Experimental evidence to support using cobalt instead of gold, the standard flux measuring medium, for measurments of reactor flux distributions in the SRE.

b) Experimental evidence required to evaluate the feasibility of using neutron-sensitive thermopiles to make direct measurements of absolute and relative flux distribution.

c) Ten independent low-power measurements of the axial flux distribution in the SRE.

The values shown below, for absolute thermal flux distributions at the core-reflector interface and at the reactor midplane in core channels R-50 and R-60 with reactor power steady at "P," were estimated in order to calculate wire exposure times:

	R-50	R-60
Core-reflector interface	2.8×10^{10} n/cm^2-sec	1.9×10^{10}
Reactor midplane	6.4×10^{10} n/cm^2-sec	4.5×10^{10}

APPENDIX

A. SCHEDULE

The estimated time required to expose six gold wires and two cobalt wires is 16 hours. Thermopile traverses in R-50 and R-60 will require approximately 3 hours. The transfer of irradiated wires to the shield casks and the removal of support tubes from the reactor is expected to require a total of four hours. The total time allotted for the experiment is 24 hours.

B. MANPOWER REQUIREMENTS

The Experimental Unit will supply one engineer and one assistant per shift to direct and conduct the experiment. The Operations Unit will supply a normal operating crew to operate the reactor. Health Physics will supply one man to perform radiation and contamination surveys. The Radiation Measurements Unit will perform the analysis of the irradiated wires.

C. EQUIPMENT REQUIREMENTS

9 wire support tubes with attached suspension cables and positioning caps.

6 nine-foot strands of gold wire ~0.020 inch in diameter.

2 nine-foot strands of cobalt wire ~0.040 inch in diameter.

1 nine-foot strand of stainless-steel wire ~0.020 inch in diameter.

2 special graphite-filled Zircaloy-2 corner channel thimbles.

2 shield casks.

2 two-region shield plugs.

1 two-channel Sanborn Recorder.

1 Leeds and Northrup potentiometer.

2 Nuclear Chicago thermopiles.

1 stop watch.

D. CREDIBLE ACCIDENTS

Throughout this experiment, the reactor will be operated under zero-power conditions. No scram interlocks will be bypassed.

The worth of the cadmium sleeves surrounding a single flux measuring wire has been estimated to be 0.2 dollar. The positive reactor period resulting from the instantaneous withdrawal of 0.2 dollar approximates 35 seconds.

Health Physics monitoring services will be used to insure personnel safety during the period of this experiment in which it is necessary for personnel to operate in the immediate area of the unshielded Zircaloy-2 thimbles.

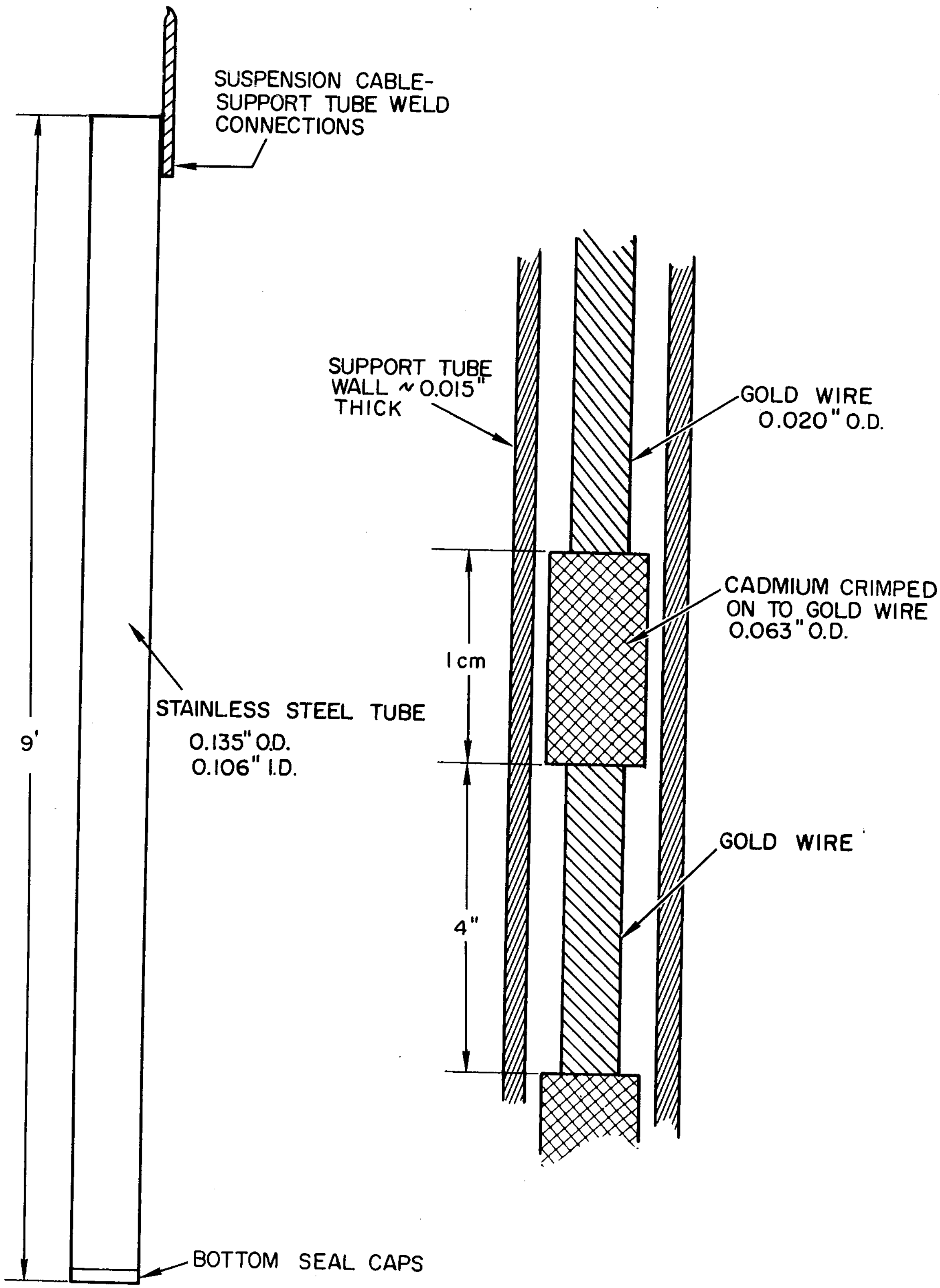


Figure VII-1. Gold Wire Assembly Inserted in Steel Support Tube

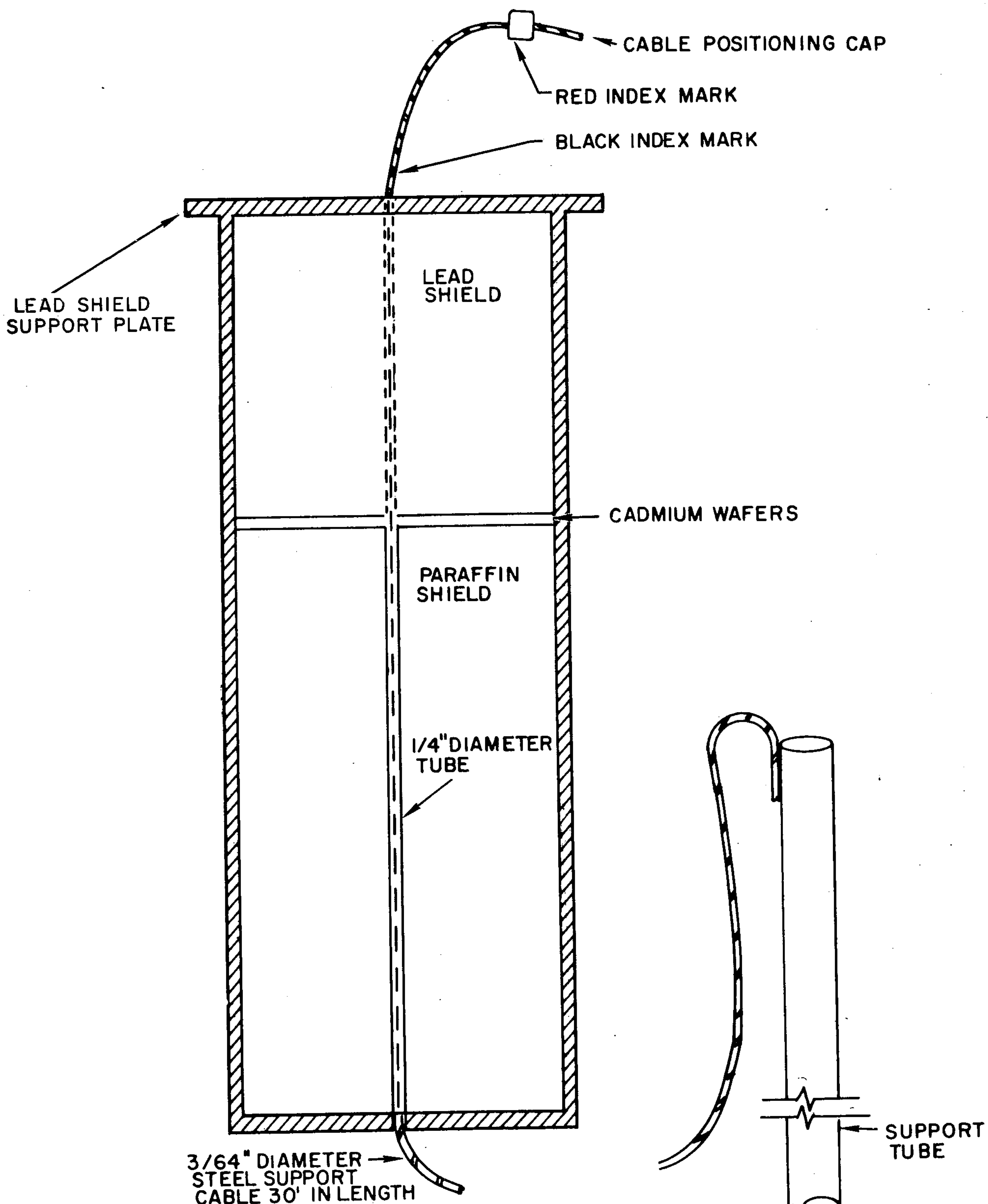


Figure VII-2. Installation of Suspension Cable in Shield

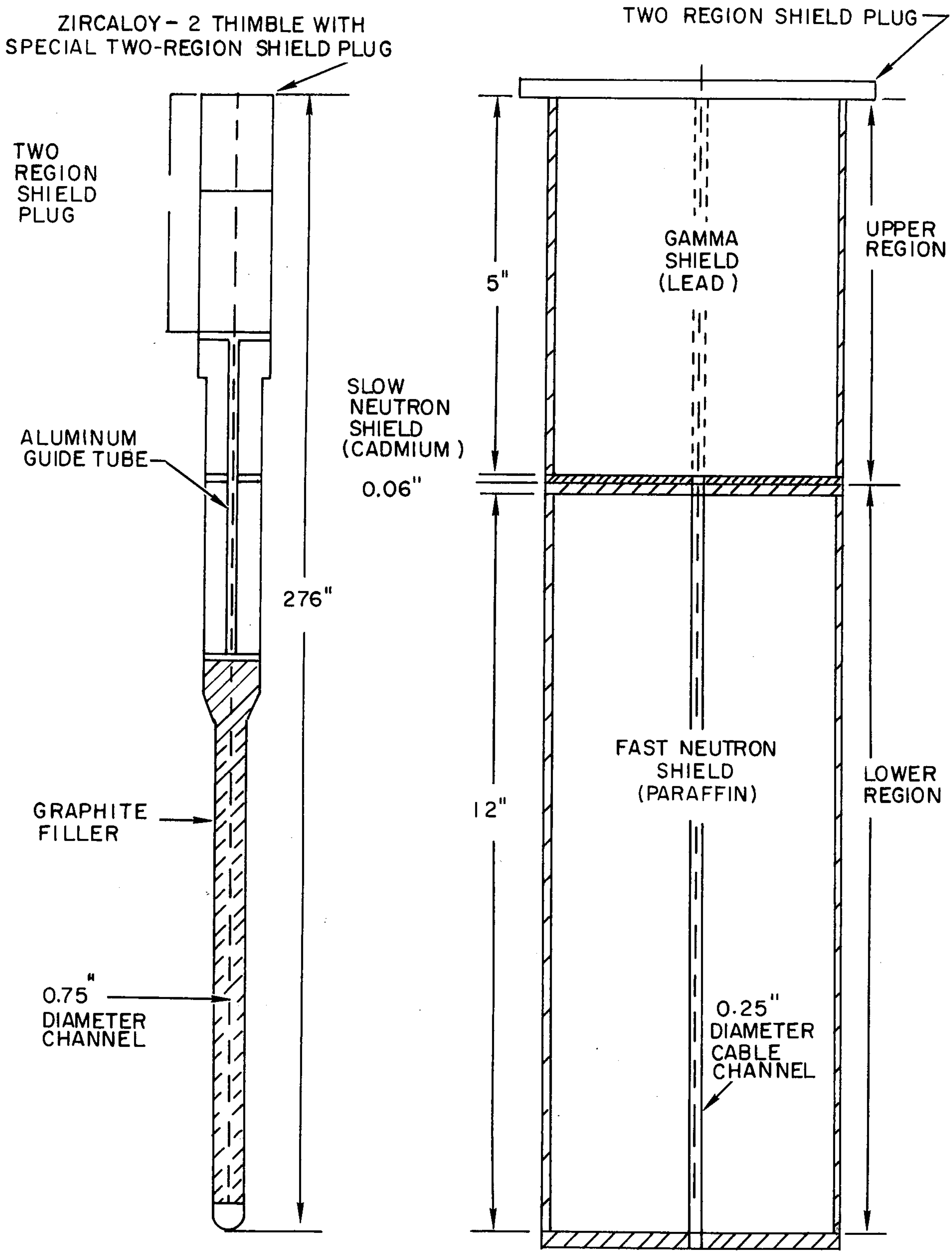


Figure VII-3. Zircaloy Thimble with Shield Assembly

WIRE IRRADIATION DATA SHEET

		Stainless Steel	Cobalt		Gold					
		R-50 4"*	R-50 4"	R-60 4"	R-50 4"	R-60 4"	R-50 6"	R-50 8"	R-50 10"	R-50 12"
Reactor Temperature	Inlet (°F)									
	Outlet (°F)									
Shim Rod Positions (V.U.)	1									
	2									
	3									
	4									
Log N Recorder Reading (%)										
Insertion Time (High Bay Clock)	Hours									
	Minutes									
	Seconds									
Position of Shim Rod No. 3										
Removal Time (High Bay Clock)	Hours									
	Minutes									
	Seconds									
Position of Shim Rod No. 3 (Step No. 26)										
Total Exposure Time Read with Stop Watch	Minutes									
	Seconds									

*Designates Cadmium Sleeve Spacing

Figure VII-4. Axial Flux Data Form
(Sheet 1 of 2)

THERMOPILE DATA SHEET

Cable Index Marks	R-50					R-60				
	Thermopile Signal (mv)	Reactor Temperature		Shim Rod 3 Position (V.U.)	Log N Recorder Reading (%)	Thermopile Signal (mv)	Reactor Temperature		Shim Rod 3 Position (V.U.)	Log N Recorder Reading (%)
		Inlet (°F)	Outlet (°F)				Inlet (°F)	Outlet (°F)		
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										
17										
18										

Remarks:

Figure VII-4. Axial Flux Data Form
(Sheet 2 of 2)

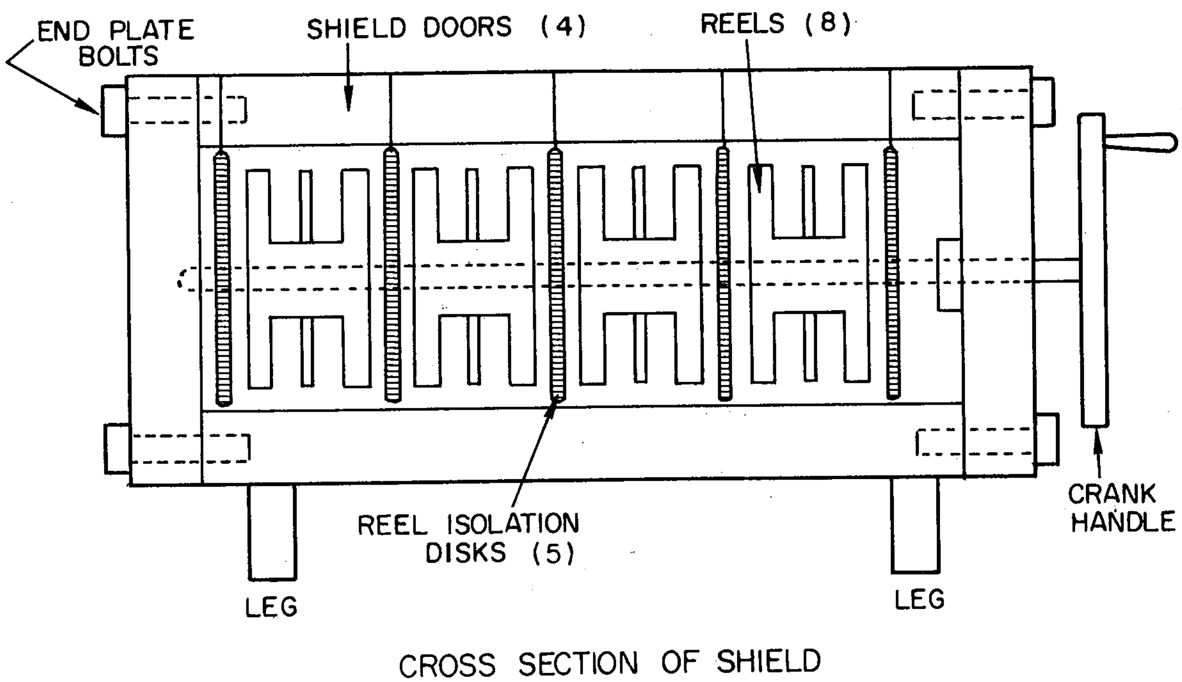


Figure VII-5. Cable Shield

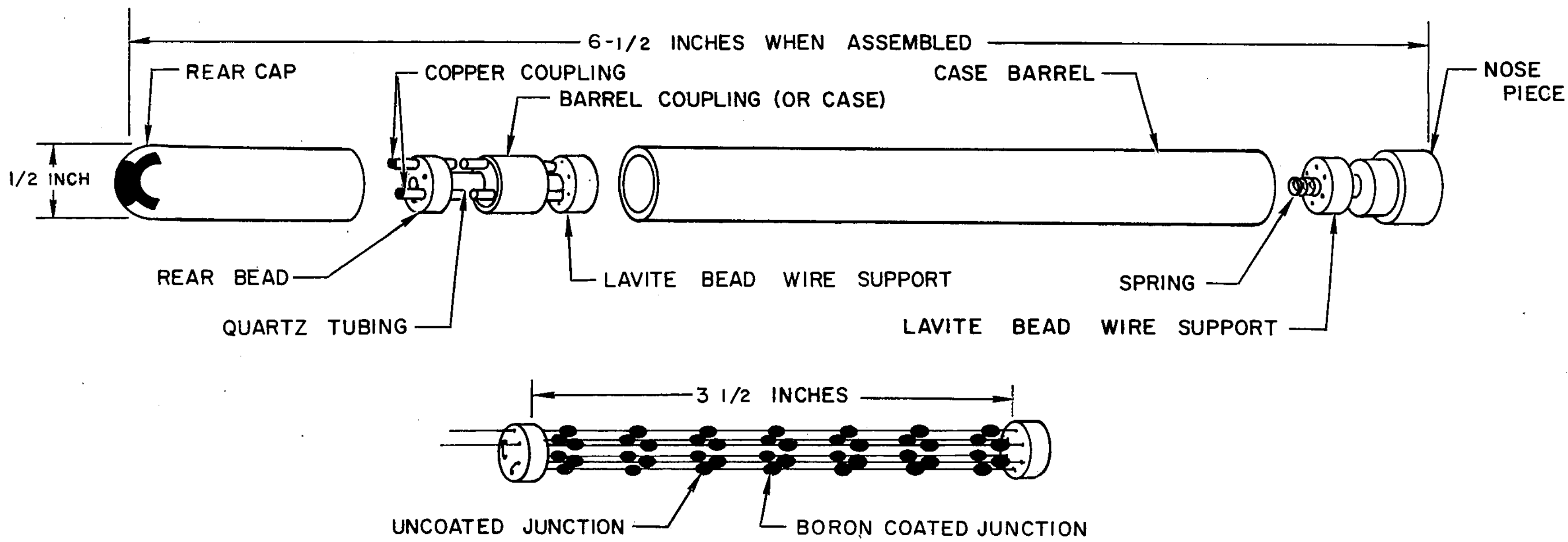


Figure VII-6. Neutron Thermopile

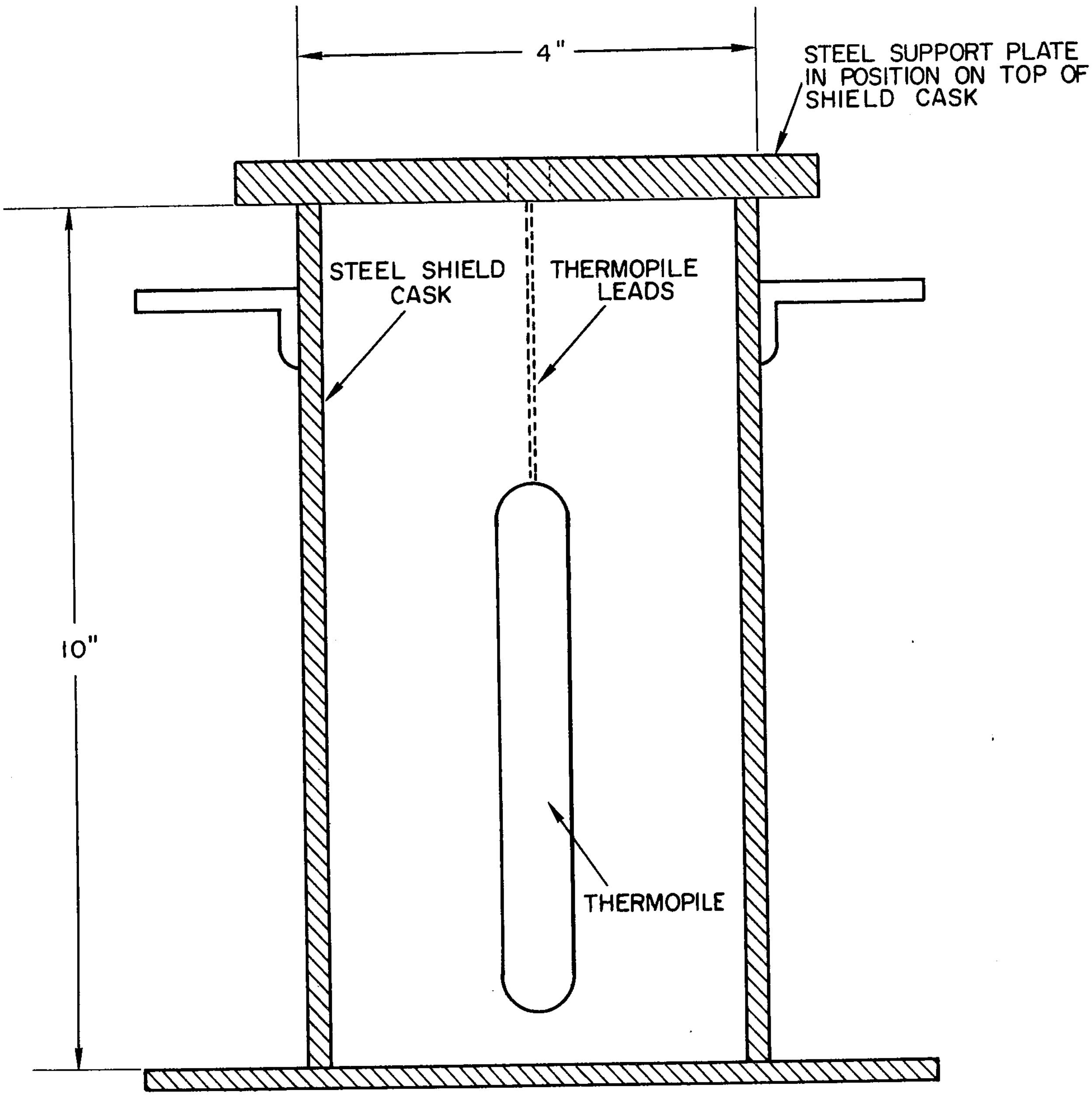


Figure VII-7. Thermopile Shield Cask

VIII

NOISE ANALYSIS

By
R. W. KEATEN

CONTENTS

TABLE

FIGURES

OBJECTIVE

The objective of this experiment is to measure the amplitude of the zero-power transfer function of the SRE using the noise analysis technique.

PURPOSE

The measurements will make possible further development of the noise analysis technique, which may eventually replace reactor oscillation as a method of measuring the amplitude of the reactor transfer function in the high-frequency range.

METHOD

I. THEORY

When a reactor is operating at a steady level, there are random fluctuations, or noise, in the neutron density, which are caused by the statistical nature of nuclear fission. It is possible to prove that because of the nature of the fission process, all frequencies of noise are equally probable, i.e., the Fourier transform of the noise signal is constant with frequency.* Noise having this property is referred to as "white noise."

This noise from the fission process is modified by the reactor, in particular by the properties of the delayed neutrons and by the prompt neutron lifetime. The modification can be expressed by the reactor transfer function, $Y_r(j\omega)$, where ω is the frequency of the signal, and $j = \sqrt{-1}$.

Let G_{xx} be the power spectral density of the noise from the fission process, i.e. the square of the amplitude of the noise signal. It is not a function of frequency, since the noise is white noise. The output noise from the reactor can be shown to be*

$$\left| Y_r(j\omega) \right|^2 G_{xx} ,$$

*J. H. Laning and R. H. Battin, Random Processes in Automatic Control (New York: McGraw-Hill Book Co., 1956) where $|Y_r(j\omega)|^2$ is the square of the amplitude of the transfer function at frequency ω.

By measuring the output power spectral density as a function of frequency, we can thus determine the amplitude of the transfer function. Plots of the transfer function are shown in Figure VIII-1 for different values of ℓ/β, the ratio of the prompt neutron lifetime to the effective fraction of delayed neutrons. By fitting the measured transfer function to the calculated functions, the value of ℓ/β in the SRE can be determined.

A block diagram of the circuit for measuring the output power spectral density is shown in Figure VIII-2. The output signal from the reactor is amplified and the steady-state signal eliminated. The remaining signal, which is the noise, is passed through a bandpass filter to select the desired range of frequencies, then to a squaring and averaging device. The output from the latter, denoted by $G_{yy}(\omega)$, is the power spectral density corresponding to the frequency range selected by the bandpass filter.

The transfer function of the circuit, and the random noise generated in the circuit and the ionization chamber, cause perturbations in the output from the circuit. Let $Y_c(j\omega)$ be the transfer function of the circuit, G_{zz} be the power spectral density of the noise from the ionization chamber (which is white noise), and $G_{nn}(\omega)$ be the power spectral density of the random noise in the circuit (not necessarily white noise). Then the output from the circuit is

$$G_{yy}(\omega) = |Y_r(j\omega)|^2 |Y_c(j\omega)|^2 G_{xx} + |Y_c(j\omega)|^2 G_{zz} + |Y_c'(j\omega)|^2 G_{nn}(\omega), \quad \ldots(1)$$

where $Y_c'(j\omega)$, the transfer function seen by the random noise in the circuit, is different from $Y_c(j\omega)$ since not all of the noise passes through the entire circuit.

To obtain $Y_r(j\omega)$, two additional measurements are necessary. In the first, the signal from a gamma source is measured with the same circuit. This source also generates white noise, but the noise is unmodified by the reactor transfer function. The output from the circuit in this case is

$$G_{yy}'(\omega) = |Y_c(j\omega)|^2 G_{zz}' + |Y_c'(j\omega)|^2 G_{nn}(\omega), \quad \ldots(2)$$

where G'_{zz} is the composite white noise from the gamma source and the ionization chamber.

The final measurement is made with no input to the circuit, so that the output is caused by the random noise generated in the circuit; i.e.,

$$G''_{yy}(\omega) = |Y'_c(j\omega)|^2 G_{nn}(\omega) \ . \qquad \ldots(3)$$

Combining the results of the three measurements gives

$$\frac{G_{yy}(\omega) - G''_{yy}(\omega)}{G'_{yy}(\omega) - G''_{yy}(\omega)} = C_1 \left| Y_r(j\omega) \right|^2 + C_2 , \qquad \ldots(4)$$

where C_1 and C_2 are constants. C_1 can be found by normalizing the experimental data to theoretical calculations in the range where $Y_r(j\omega)$ is independent of ℓ/β (see Figure VIII-1). C_2 is obtained from the measurements at high frequencies, where $|Y_r(j\omega)|$ is essentially zero.

II. METHOD OF MEASUREMENT

A circuit diagram of the apparatus is shown in Figure VIII-3. The signal from the ionization chamber is detected and amplified with a Keithley micromicroammeter. The bucking voltage is adjusted with HP_1 until the steady-state signal is eliminated, then the resulting noise signal is amplified with A_1. The bandpass filter is set to pass a narrow range of frequencies. The signal is then passed through a vacuum thermocouple, which serves as a squaring device. Two Zener diodes in parallel with the thermocouple act as current limiters to protect the thermocouple.

Two methods will be used to integrate and read out the signal from the thermocouple. In the first (the original method) the signal is integrated in the circuit containing A_2, then read out on a Sanborn Recorder. The recorder output divided by time is then the average power spectral density.

In the new method, the signal from the thermocouple is fed to a voltage-frequency converter, which puts out a signal of constant amplitude with a frequency proportional to the amplitude of the input signal. The output signal goes to a scaler and printer. The count rate of the scaler is then the average power spectral density.

Both methods will be used in order to evaluate the accuracy of the new method.

Three sets of measurements will be taken: one with the reactor signal, one with the signal from the gamma source, and one with no input to the circuit. For each set, measurements will be made from 0.02 cps to about 2 kc. At each frequency, the width of the bandpass will be 10% of the average frequency.

The results will be analyzed by the method discussed in the previous section, in order to obtain the amplitude of the transfer function as a function of frequency, which will then be compared to the results of the experiments with the reactor oscillator in order to evaluate the noise analysis technique.

PROCEDURE

Parts I, II, III do not require the use of the reactor, and should be done as soon as possible.

I. EQUIPMENT SETUP

1.(E) The rack containing the noise analysis equipment, the Sanborn Recorder, and the scaler-printer will be used in the Sanborn room. The Keithley ammeter must be placed in the high-bay area close to the reactor loading face.

2.(E) Run a cable from the output of the Keithley ammeter to the connector marked SIGNAL INPUT on the noise analysis rack.

3.(E) Connect one input of the dual trace oscilloscope to the input of the bandpass filter, and the other input to the output of the filter. Zero both traces on the oscilloscope, and set both channels to d-c coupling.

4.(E) Connect a cable from the connector marked INTEGRATOR OUTPUT to the input of the Sanborn Recorder. Calibrate the recorder to read one millivolt per millimeter.

5. (E) Connect the output of the frequency converter to the input of the Systron scaler. Set the frequency converter for 10 volts maximum input. Set the scaler for a 10-minute counting interval.

6. (E) Open all switches shown in Figure VIII-3. Turn on the power to the amplifiers by plugging in the power to the noise analysis rack. The amplifiers must be allowed a 4-hour warmup period. After any power loss, allow a 30-minute warmup time.

7. (E) If either amplifier is allowed to saturate, it may oscillate. To stop the oscillation, pull the amplifier out of the rack.

II. MEASUREMENT OF THE CIRCUIT NOISE

1. (O,E) Pull the ionization chamber out of instrument thimble 7 and lay it on the floor of the high bay. Connect it to the input head of the Keithley ammeter. Call M. B. Ruegamer or C. W. Griffin, who will connect high voltage to the chamber. Do not connect the gamma compensation.

> NOTE: The power supply of the Keithley ammeter will be used for the high voltage to the chamber, or if this is not sufficiently free of noise, batteries will be used.

2. (E) Set the A_1 GAIN switch on the back of the noise analysis rack to the "100" position. Set the range switch on the Keithley ammeter to "3×10^{-8}". Set HP_1 to zero.

3. (E) Close S_1. The position of the traces on the oscilloscope should not change.

4. (E) Set the bandpass filter to a mid-band frequency of 0.02 cps, with a bandpass of 10%. Then close S_3.

> NOTE: Whenever S_3 is closed, watch the voltmeter. When it reads 30 volts (positive or negative), push in S_4 to short the integrating condenser. This prevents overloading the amplifier.

5. (E) Adjust the setting of the RANGE switch and the chart speed of the Sanborn Recorder to give a slope of about 45°. If this is impossible, put the

RANGE switch on maximum sensitivity. Turn on the timer on the Sanborn Recorder.

6. (E) When the adjustments are complete, short S_4 and start the run. Turn on the scaler.

7. (O,E) The following conditions must be satisfied for a run to be valid:

a) No sudden large noise pulses should appear during the run. These are produced by transients in the power line, caused by turning on or off any large power equipment. For this reason, the crane in the high bay must not be used during the run.

b) The Zener diodes should not conduct during the run. This can be observed by comparing the two traces on the oscilloscope. If the signal on the output of the bandpass filter appears clipped compared to the input signal, the data should be discarded and the run repeated. However, clipping of about one out of sixteen spikes is permissible if the clipped spike is unusually large.

c) The slope of the output on the Sanborn Recorder should not change appreciably during the run.

8. (E) Continue the run until about 10 centimeters of good data are taken on the Sanborn Recorder. Then stop the scaler, short the integrating condenser, and open S_3.

9. (E) Record on the data sheet all required information. Record on the Sanborn chart the run number, type of noise measured (circuit, gamma source, or reactor), mid-band frequency, RANGE switch setting, chart speed, and A_1 gain. Record on the tape from the printer the run number, type of noise measured, mid-band frequency, counting time, range setting on the voltage-frequency converter, and A_1 gain.

ALL DATA MUST BE RECORDED BEFORE PROCEEDING.

10. (E) Repeat Steps 4 through 10, using the mid-band frequencies listed in Table VIII-1. Do not change the setting of the A_1 GAIN switch. The Sanborn RANGE switch setting and chart speed, the input range switch on the frequency converter, and the counting time of the scaler may be changed when desirable.

NOTE: Be certain that S_3 is open before changing the range switch on the bandpass filter.

TABLE VIII-1

MID-BAND FREQUENCIES USED IN NOISE MEASUREMENTS (cps)

0.02	0.04	0.06	0.08					
0.10	0.15	0.20	0.30	0.40	0.50	0.60	0.80	
1.0	1.2	1.4	1.6	1.8	2.0	2.3	2.7	
3.0	3.5	4.0	5.0	6.0	7.0	8.0	9.0	
10.0	15.0	20	30	40	50	60	70	80
100	120	150	200	300	500	800		
1000	1500	2000						

11.(E) When measurements have been made at all the frequencies listed in Table VIII-1, change the setting of the A_1 GAIN switch to "1000". Measure the noise at 2 kc, then stepwise decrease the frequency, making measurements at the same frequencies as before. For each frequency follow the procedure given in Steps 4 through 9. Continue decreasing the frequency until the noise pulses are too large to measure at this gain setting.

12.(E) Analyze the data by the method given in Steps 1 through 6 in Part V. Remeasure any questionable points before proceeding to the next part.

III. MEASUREMENT OF THE GAMMA SOURCE NOISE

1.(E,H) Request the assistance of Health Physics. Bring the 70 millicurie cobalt gamma source into the high-bay area and lay it on the floor close to the ionization chamber. Rope off the area surrounding the source.

2.(E,H) Adjust the position of the source relative to the ionization chamber to obtain a reading of about 50% on the "3×10^{-8}" scale of the Keithley ammeter.

3.(E) Set HP_1 to 10 times the reading on the Keithley ammeter, which gives approximately the required bucking voltage. (For example, if the reading on the Keithley ammeter is 50%, set HP_1 to "500".)

4. (E) Set the oscilloscope for d-c coupling, and be certain that the traces are zeroed. Set the A_1 GAIN switch to "1".

5. (E) Be certain that S_3 is open, then simultaneously close S_1 and S_2. Adjust HP_1 until the traces on the oscilloscope are back to the zero position.

6. (E) Change the A_1 GAIN switch to "10" and readjust HP_1. Then increase the gain to "100" and readjust. Record on a data sheet similar to Figure VIII-4 the final setting of HP_1.

7. (E) Measure the power spectral density of the gamma source noise by the method given in Steps 4 through 11 of Part II. Be certain that all measurements are at exactly the same frequencies as used in Part II, and that the settings of the A_1 GAIN switch are the same.

8. (E) When the measurements are complete, analyze the data by the method given in Steps 1 through 6 in Part V. Complete the analysis and re-measure any questionable points before proceeding to the next part.

9. (E,H) Remove the gamma source from the high-bay area.

IV. MEASUREMENT OF THE REACTOR NOISE

1. (O,E) Put the ionization chamber back into instrument thimble 7. Insert it as far as possible. Connect the high voltage and the gamma compensation to the chamber. (Use either the Keithley power supply or batteries, as in Step 1, Part III.)

2. (O) Start up the reactor and raise the power until the reading on the Keithley ammeter is about 70% on the "3×10^{-8}" scale. This should be between points "A" and "B" on the log N recorder. Then put the reactor on automatic control until the power is level. Maintain the average of the main primary inlet and outlet temperatures at 340°F. Maintain the main primary flow at 1000 gpm. Shut off the auxiliary primary flow. When the reactor power is level, put the reactor back on manual control.

3. (E) Measure the power spectral density of the reactor noise by the method given in Steps 3 through 7 of Part III. Use the same frequencies and the same settings of the A_1 GAIN switch as before.

4. (E) When the measurements are complete, analyze the data by the method given in Part V.

V. ANALYSIS OF DATA

1. Draw a straight line through the output trace of the Sanborn Recorder. If the trace is so curved that it is not possible to draw a single straight line, repeat the run.

2. Extend the line as far as possible, and mark the endpoints of the line.

3. Find the time interval between the endpoints of the line from the timing markers generated by the Sanborn Recorder. Record this time on a data sheet similar to Figure VIII-4.

4. Find the difference in the output level of the two endpoints in millimeters, and record it on the data sheet. Convert millimeters to volts by multiplying the number of volts per millimeter corresponding by the setting of the RANGE switch. Record this on the data sheet.

5. Divide the number of volts by the time (in seconds); for measurements in Part II, call this $G''_{yy}(\omega)$; for measurements in Parts III and IV, call it $G'_{yy}(\omega)$ and $G_{yy}(\omega)$, respectively. Record the values on the data sheet.

6. Divide the number of counts recorded on the scaler by the counting time, then multiply by the setting of the attenuator range switch on the V-F converter and record this number on the data sheet. Give it the same designation as in Step 5. This number should be equal to that obtained in Step 5 if the voltage-frequency converter and scaler are operating properly.

> <u>NOTE</u>: If the early measurements show that the voltage-frequency converter and scaler will give accurate data in agreement with the data from the Sanborn Recorder, then only the data from the scaler need be analyzed.

7. When all measurements are complete and have been analyzed by the above method, calculate the following quantity for each frequency:

$$X = \frac{G_{yy}(\omega) - G''_{yy}(\omega)}{G'_{yy}(\omega) - G''_{yy}(\omega)} .$$

Record these values on the data sheet. Do the same for measurements with an A_1 gain of "1000".

8. The square root of X is proportional to the amplitude of the reactor transfer function at frequency ω. Plot this as a function of frequency. Normalize the two curves with different A_1 gains in the region where they overlap.

NOTE: At high frequencies, the plot will level out at a constant value, which is C_2 in Equation (4). If this value is not negligible at low frequencies (0.02 – 20 cps), recalculate the amplitude of the transfer function by the relation

$$|Y_r(j\omega)| = (X - C_2)^{1/2} .$$

9. Normalize the experimental plot to the theoretical curves at the low-frequency end, and then compare the experimental and theoretical curves. If any points look questionable, re-measure them.

10. From the above comparison, determine the value of ℓ/β, and compare this with the value obtained from the measurements with the reactor oscillator. If the two agree within experimental error, the experiment is finished.

EXPECTED RESULTS

The noise analysis measurements will yield a curve similar to those shown in Figure VIII-1. The value of ℓ/β obtained from the curves should be about the same as in the first core, where it was 0.075 seconds.*

The evaluation of the new method for integrating and averaging the data, i.e., the use of the voltage-frequency converter and scaler, will demonstrate that this method gives more accurate data than the original method, and that the analysis of the data is much easier and faster.

*C. W. Griffin and J. G. Lundholm, Jr., "Measurement of the SRE and KEWB Prompt Neutron Lifetime using Random Noise and Reactor Oscillation Techniques," NAA-SR-3765, 1959

EXPECTED CONCLUSIONS

The noise analysis technique will provide an accurate and convenient method of measuring the amplitude of the reactor transfer function in the high-frequency region. Due to its simplicity, this method will eventually replace the reactor oscillation measurements in the high-frequency region.

APPENDIX

A. SCHEDULE

The experiment will require approximately two days (six shifts).

B. MANPOWER REQUIREMENTS

The Operations crew and two people from the Experimental unit will be required for each shift. In addition, C. W. Griffin and M. B. Ruegamer will be available to advise and assist when necessary.

C. EQUIPMENT REQUIREMENTS

1 ionization chamber
1 Keithley micro-microammeter
1 Tektronix Model 535 dual trace oscilloscope
1 voltage-to-frequency converter
1 Systron scaler
1 Sanborn Recorder
2 Kintel operational amplifiers
1 Kronkite band pass filter

Miscellaneous electrical equipment shown in Figure VIII-3.

D. CREDIBLE ACCIDENTS

The reactor will be used only in Part IV of these procedures, where it will be run at a steady level at low power. The measurements will not affect the operation of the reactor, and no safety interlocks will be bypassed; hence, no hazards will exist.

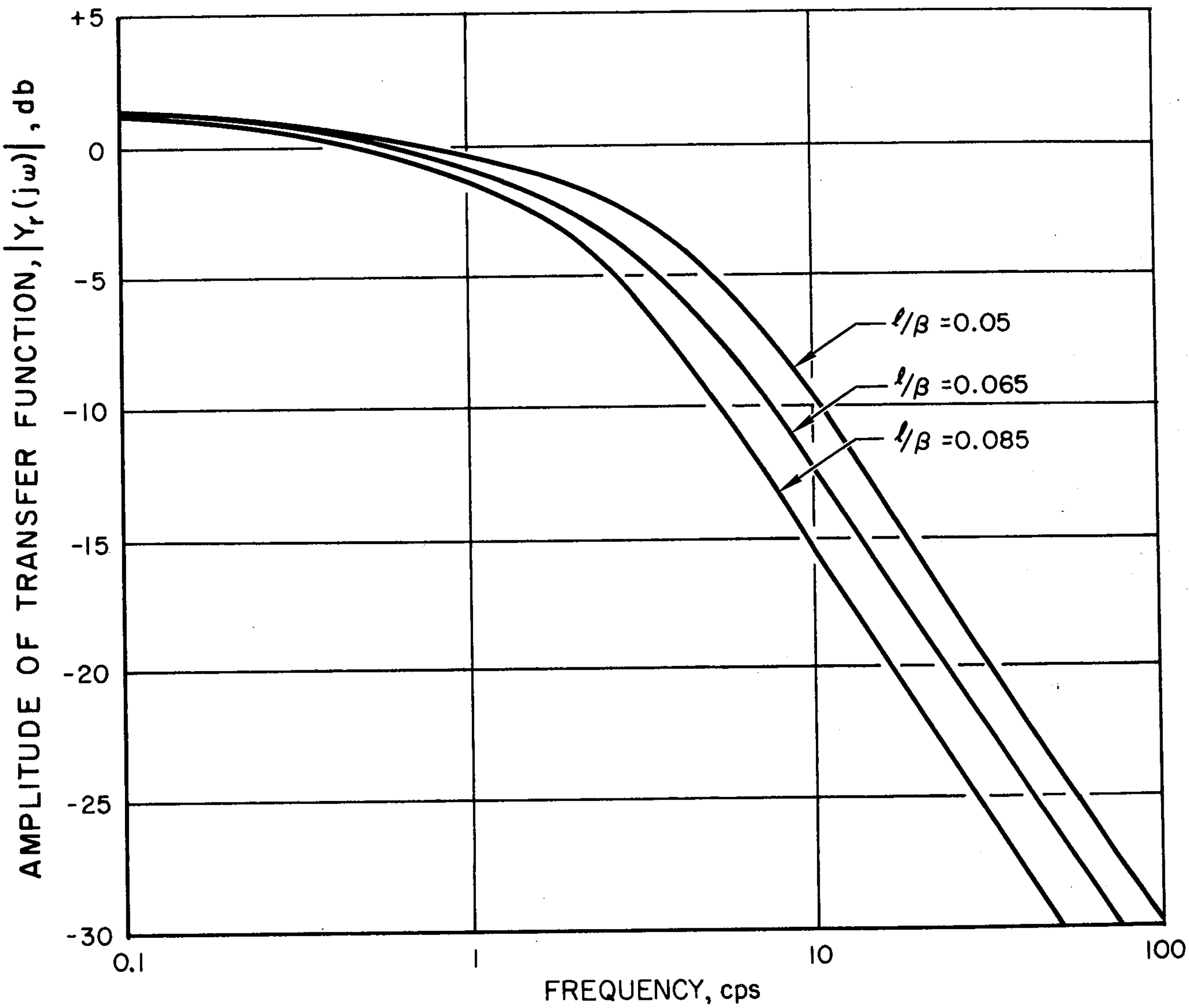


Figure VIII-1. Amplitude of Reactor Transfer Function vs Frequency

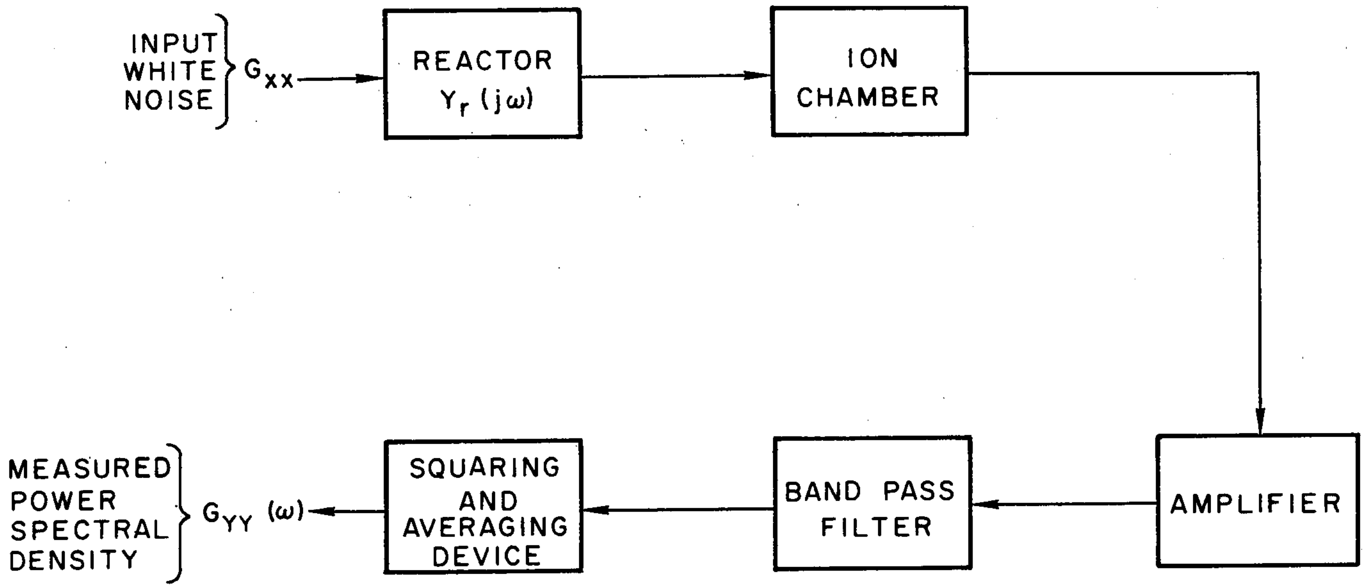


Figure VIII-2. Basic Circuit for Power Spectral Density Measurements

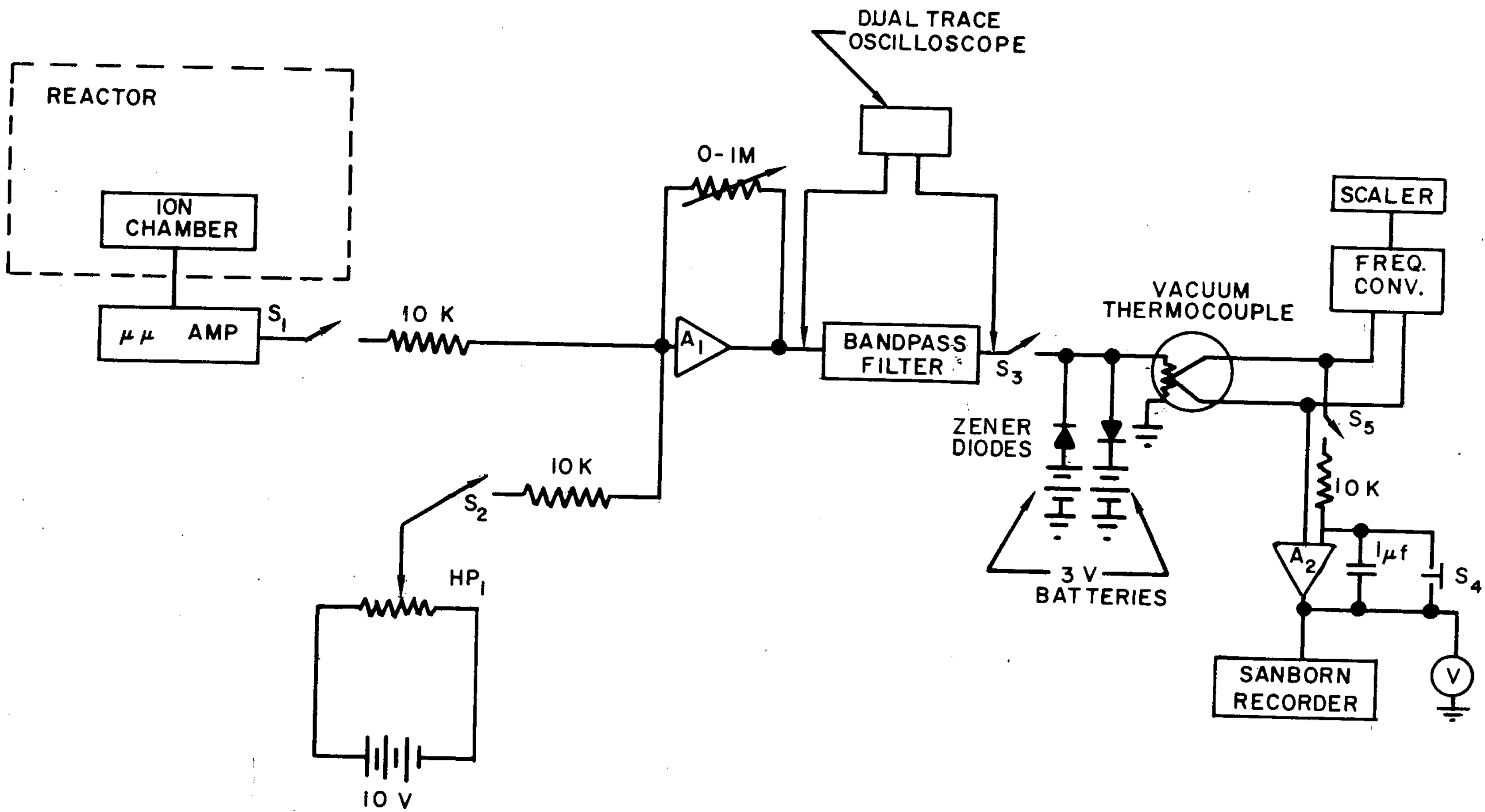


Figure VIII-3. Circuit Diagram of Noise Analysis Equipment

Run Number		1	2	3	etc.
Type of Noise Measured					
Log N Reading					
Primary Na Temp °F	Inlet				
	Outlet				
	Average				
Band Pass Filter Settings (cps)	High Frequency				
	Low Frequency				
	Average Frequency				
A_1 Gain					
HP_1 Setting					
Sanborn Recorder	Range Switch				
	Chart Speed				
Range Setting on V-F Converter					
Scaler Counting Time (sec)					
Sanborn Output (mm)					
Sanborn Output (volts)					
Sanborn Time Interval (sec)					
Scaler Total Counts					
$G_{yy}(j\omega)$ from Sanborn					
$G_{yy}(j\omega)$ from Scaler					
X					
$\sqrt{X} = \|Y_r(j\omega)\|$					

Figure VIII-4. Data Sheet for Noise Analysis Measurements

IX

AXIAL STATISTICAL WEIGHT

By
R. A. MOSER

CONTENTS

FIGURES

OBJECTIVE

The objective of this experiment is to determine the axial statistical weight of an SRE thorium 7.6 wt-% uranium core with an operational fuel loading.

PURPOSE

The axial statistical weight is necessary for calculating reactivity changes resulting from variations in the constituents or conditions of a cell, e.g. xenon, fuel, and temperature. Further, axial statistical weight values are necessary for separating fuel, coolant, and graphite contributions to the power coefficient as measured with a reactor oscillator.

METHOD

With the reactor in an isothermal condition at approximately 340°F, and with a Zircaloy-2 thimble in the core, the shim rods will be withdrawn to establish a constant flux,"B." The shim rod configuration will then be measured.

A neutron absorber (Figure IX-1) will be lowered down the Zircaloy-2 thimble in 6-inch increments, starting at the top of the reflector and continuing until the core has been traversed. The shim rod configuration required to maintain reactor power at "B" after each movement of the absorber will be measured.

The change in reactivity as a function of the axial position of the absorber can be calculated by integrating the worth of shim rod 3 between its position with the absorber in the core and its position out of the core. This change will be plotted as a function of absorber position. The axial statistical weight will be found by normalizing the area under the curve to unity.

PROCEDURE

1. (O,E) Insert an empty Zircaloy-2 thimble in R-50 and a corner channel dummy fuel assembly into R-60. Mount the absorber suspension assembly over the thimble in R-50 (see Figure IX-2).

2. (O) Maintain the core in an isothermal condition at 340°F. Line heaters and, if necessary, pool heaters are to be used to control reactor temperature.

3. (O) Maintain a constant flow rate of 1000 gpm in the main primary sodium loop during measurement sequences. There should be no flow in the auxiliary primary coolant loop.

4. (O) Withdraw the safety rods to their upper limits.

5. (O) Withdraw shim rod 3 to 36 inches out.

6. (O) Individually withdraw shim rods 1, 2, and 4 the same distance from their lower limit switches such that the reactor is critical, and power is steady at point "B." The power value for "B" will have been established in Experiment III.

7. (E) Record the positions of shim rods 1, 2, and 4 on the axial statistical weight data form (see Figure IX-3). Shim rods 1, 2, and 4 MUST NOT be moved after this initial positioning step.

8. (O) Steady reactor power at point "B" for twenty minutes by adjusting shim rod 3 only.

9. (O, E) After reactor power has been steady at "B" for twenty minutes, record the reactor power level, as indicated on the log N recorder, on the data form. This log N value should be used as a reference value in making all further power adjustments to point "B."

10. (E) Record the core temperature (the average of the reactor inlet and outlet temperatures) and the position of shim rod 3 on the data form. Designate the position of shim rod 3 in this configuration as "x_{oo}."

11. (E) Slowly insert the neutron absorber into the thimble until the first cable marker is at the cable vice index point (see Figure IX-2). The absorber is now positioned with its centerline at the top of the upper reflector, i.e. at the top of the graphite.

12. (O) Adjust the position of shim rod 3 as the absorber is lowered to permit holding power steady at "B."

13. (O) Repeat Steps 8 and 10. Designate the position of shim rod 3 in this configuration as "x_o."

14. (E, O) Lower the neutron absorber to the next "6-inch" cable marker while compensating with shim rod 3.

15. (O, E) Repeat Steps 8 and 10. Designate the position of shim rod 3 in this configuration as "x_1."

16. (O, E) Repeat Steps 14 and 15 until the absorber has traversed the upper reflector and core. Designate the positions of shim rod 3 in these configurations as x_2, x_3, . . . , x_{15}.

17. (E) Slowly withdraw the absorber from its lower limit position to the "zero distance" position while compensating with shim rod 3. The zero distance is the first cable marker. (See Step 11.)

18. (O, E) Repeat Steps 8 and 10. Designate the position of shim rod 3 in this configuration as "x'_o."

19. (E) Withdraw the absorber to its upper limit, compensating as necessary with shim rod 3. Health Physics monitoring will be required during this step. Beta-gamma surveys should be made in the area of the absorber suspension assembly as the absorber is withdrawn to its upper limit. These surveys will provide a measurement of any induced radioactivity associated with the absorber.

20. (O, E) Repeat Steps 8 and 10. Designate the position of shim rod 3 as "x'_{oo}."

21. (O) Shut down the reactor.

22. (E) Remove the absorber and suspension assembly from the measurement thimble. Place the absorber in the shield cask (see Figure IX-4). Store the cask in accordance with Health Physics instructions.

23. (E) Record the Veeder readings on each of the four shim rod drives immediately prior to their removal from the reactor loading face.

24. (O, E) Remove the TV equipment and safety-and shim-rod drives from the reactor loading face. Care should be taken to prevent turning the shim-rod drive shafts during or after this removal operation. Veeder counter attachment and shim rod lower limit positions should not be altered without prior notification of the Experimental engineer.

25. (E) Record the Veeder readings in shim rod thimbles 1 and 2.

26. (O) Load an empty Zircaloy-2 thimble in R-60 and a corner channel dummy fuel assembly in R-50.

27. (O, E) Prepare to replace the shim rod drives. Just prior to replacing the shim rod drives, check to make certain that the Veeder readings on each shim rod drive, as well as those in thimbles 1 and 2, have not been altered. Replace the shim- and safety-rod drives, TV equipment, etc.

28. (E) Mount the absorber suspension assembly over R-60.

29. (O,E) Repeat Steps 4 through 8. Shim rods 1, 2, and 4 must be withdrawn to the positions established for these rods in Step 6. Final adjustment of power to "B" should be made using shim rod 3.

30. (O, E) Repeat Steps 10 through 25.

31. (O) Remove the Zircaloy-2 thimble from R-60. Replace it with a corner channel dummy.

32. (O) Repeat Step 27.

33. Proceed to the next experiment.

ANALYSIS

I. NOMENCLATURE

$$\rho_{oo} = \int_{z=o}^{z=x_{oo}} \left(\frac{d\rho}{dz}\right) dz$$

$$\rho_i = \int_{z=o}^{z=x_i} \left(\frac{d\rho}{dz}\right) dz$$

T_i = average core temperature existent during measurments with the absorber at position x_i.

I_i = change in reactivity resulting from changes in temperature between T_o and T_i.

A_i = worth of absorber.

II. PROCEDURE

The data collected will be normalized such that the integral of the worth of the absorber will be unity. A normalized curve similar to that shown in Figure IX-5 would then represent the axial statistical weight.

1. Determine ρ_o and ρ_i, using the integral shim-rod worth curve for shim rod 3, where shim rod 3 has been calibrated against the gang of shim rods 1, 2, and 4 during Experiment IV. This curve will be obtained from a shim rod calibration experiment performed prior to this experiment.

2. Calculate I_i, using the isothermal temperature coefficient curve. This curve will be obtained from data collected in Experiment X.

3. Calculate $\Delta\rho$, where

$$\Delta\rho = \rho_i - \rho_{oo} \ .$$

4. Calculate ρ_A, where

$$\rho_A = \Delta\rho + I_i.$$

5. Correct for changes in absorber position as a function of cable growth, using core temperatures and the coefficient of linear expansion of the cables.

6. Plot ρ_A as a function of the axial position of the absorber.

EXPECTED RESULTS

Although the axial statistical weight was not measured for the enriched uranium core, an estimate of it can be obtained by multiplying the calculated thermal flux and thermal adjoint.* This quantity is shown in Figure IX-5.

The axial statistical weight should behave similarly to that for the enriched uranium core.

* F. L. Fillmore, "Two-Group Calculations of the Critical Core Size of the SRE Reactor," NAA-SR-1517 (Revised), January 15, 1959.

APPENDIX

A. SCHEDULE

The reactor will be loaded in accordance with Figure IX-6 for this experiment. Loading will require insertion of Zircaloy-2 thimbles in R-50 and R-60, respectively. Estimated time required for this operation is 8 hours. The estimated time to attain criticality and traverse a single measurement channel is 12 hours.

The second channel traverse is expected to require 10 hours. The total time allotted for the experiment is 36 hours.

B. MANPOWER REQUIREMENTS

The Experimental unit will supply one engineer and one assistant per shift to direct and conduct the experiment, i. e. to operate the Sanborn Recorders, position the absorber, etc.

The Operations unit will supply the normal operating crew to operate the reactor.

C. EQUIPMENT REQUIREMENTS

1 two-channel Sanborn Recorder
1 Boral neutron absorber
1 absorber suspension assembly and shield cask
2 Zircaloy-2 corner channel thimbles

D. CREDIBLE ACCIDENTS

The worth of the absorber at the reactor midplane has been calculated to be approximately 0.4 dollar. If the absorber were to fall from the reactor midplane to the bottom of the measurement thimble, an asymptotic period of approximately 5 seconds would result if the operator did not compensate with shim rod adjustments.

During the experiment, three scram circuits will always be connected to the safety-rod holding magnets.* The high-level period amplifiers in instrument channels III and IV will ring an alarm if the period reaches 20 seconds, initiate an automatic insertion of the shim rods at 10 seconds, and scram the reactor at 5 seconds. The flux safety channels, i.e. instrument channels V and VI, will be modified to scram the reactor at 0.1% of full power. Three fuel-channel exit temperatures will be monitored. If two of them exceed 390°F, the reactor will be automatically scrammed. None of these circuits may be bypassed.

Dropping the absorber could result from two causes. First, the weight of the absorber could cause the reel to unwind. To prevent this, a friction brake has been added to the suspension assembly as shown in Figure IX-2. The brake would have to fail and the vise would have to be released before the reel could unwind. Second, either the cable or the linkage at the absorber could break. The absorber weighs 1.5 pounds and the yield strength of the cable is 350 pounds. The cable and the linkage have been tested by dropping the absorber 23 feet several times.

Provisions have been made to provide the requisite amount of shielding material, i.e. a thimble insert, to effectively reduce to tolerance levels gamma and neutron intensities extant at the top of the Zircaloy-2 thimbles at 0.1% of full power.

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* R. J. Hall, "SRE Instrumentation and Control," NAA-SR-Memo-1639.

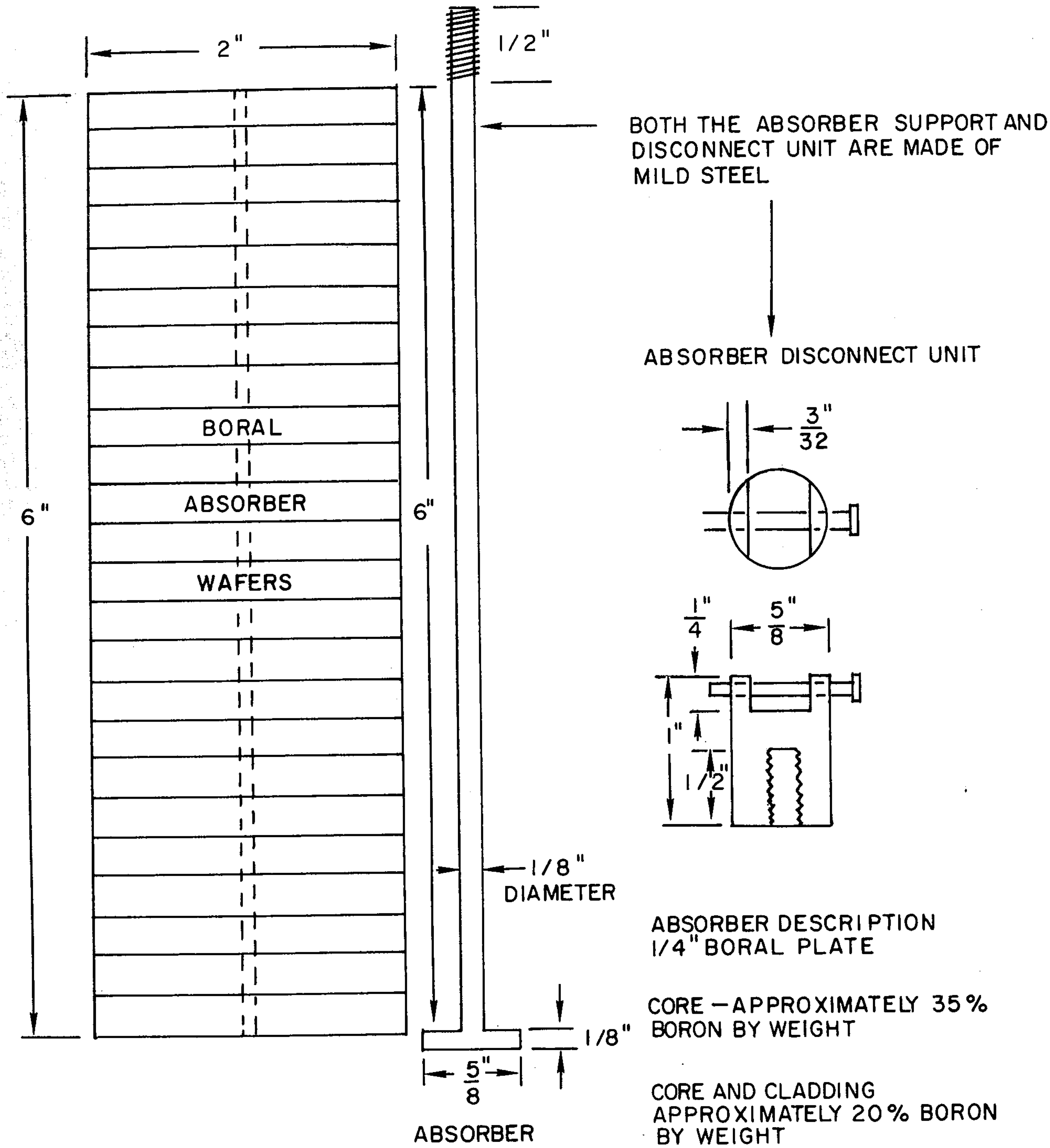


Figure IX-1. Neutron Absorber, Suspension Assembly, and Shield Cask

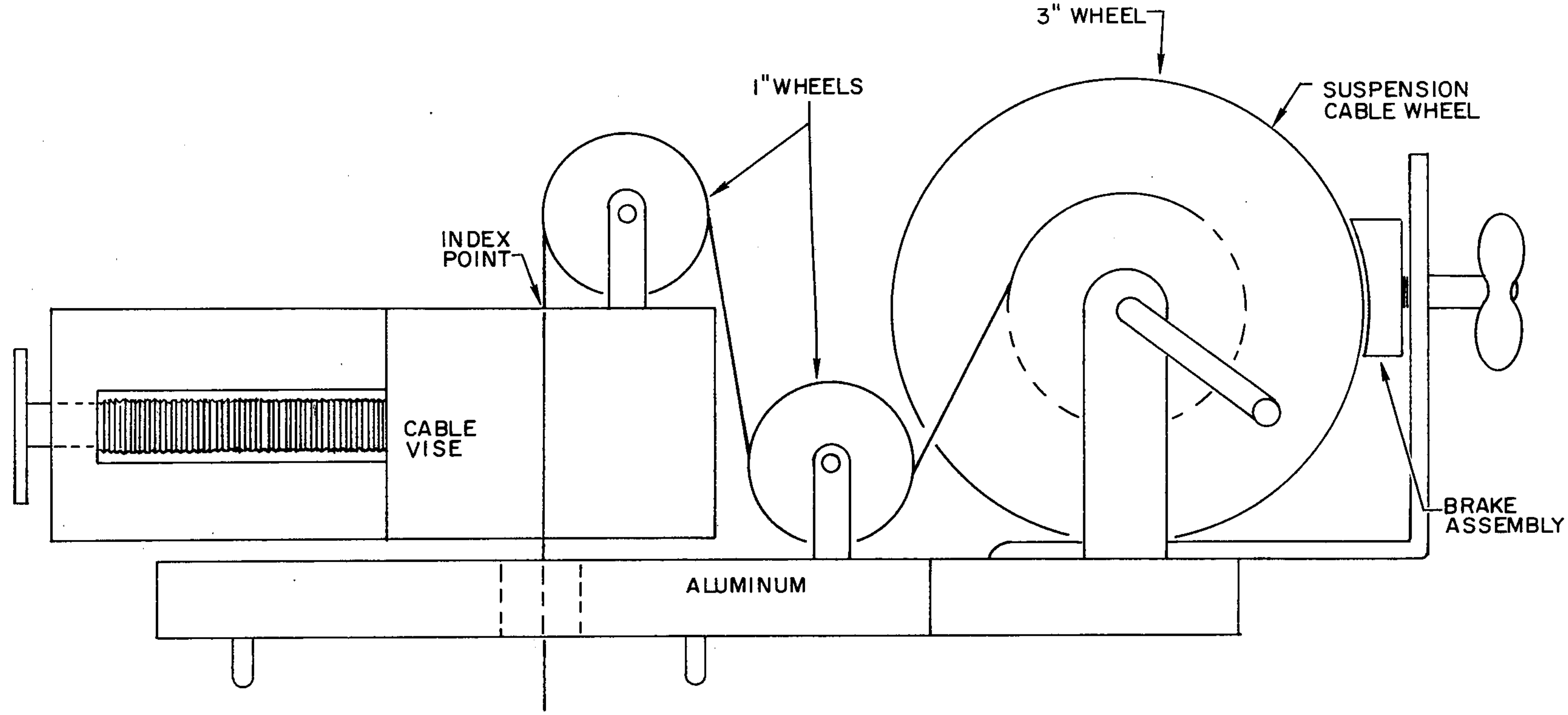
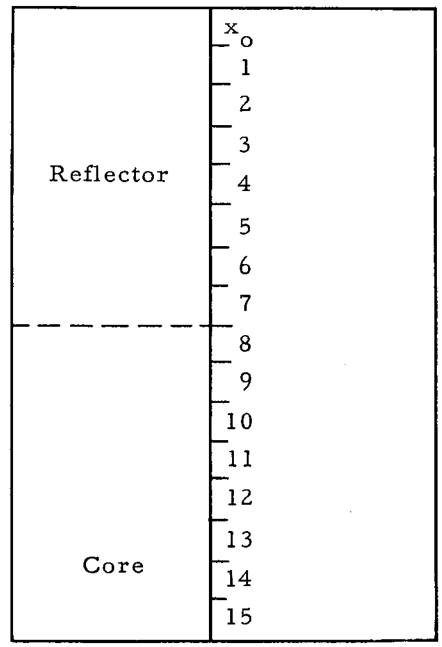


Figure IX-2. Neutron Absorber Suspension Assembly

Shim Rod No. and Position	Core Channel R-50		Core Channel R-60	
	Veeder Units	Core Temperature	Veeder Units	Core Temperature
No. 1				
No. 2				
No. 4				
No. 3				
x_{oo}				
x_{oo}'				
x_o				
x_o'				
x_1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				

1. Position Fission Chamber No. 1	
2. Position Shim Rod 1 after Disconnect	
3. Position Shim Rod 2 after Disconnect	
4. Position Shim Rod 3 after Disconnect	
5. Position Shim Rod 4 after Disconnect	
6. Veeder Reading in Thimble No. 1 after Disconnect	
7. Veeder Reading in Thimble No. 2 after Disconnect	



Position of Absorber Corresponding to Shim Rod 3 Position Data.

Figure IX-3. Axial Statistical Weight Form

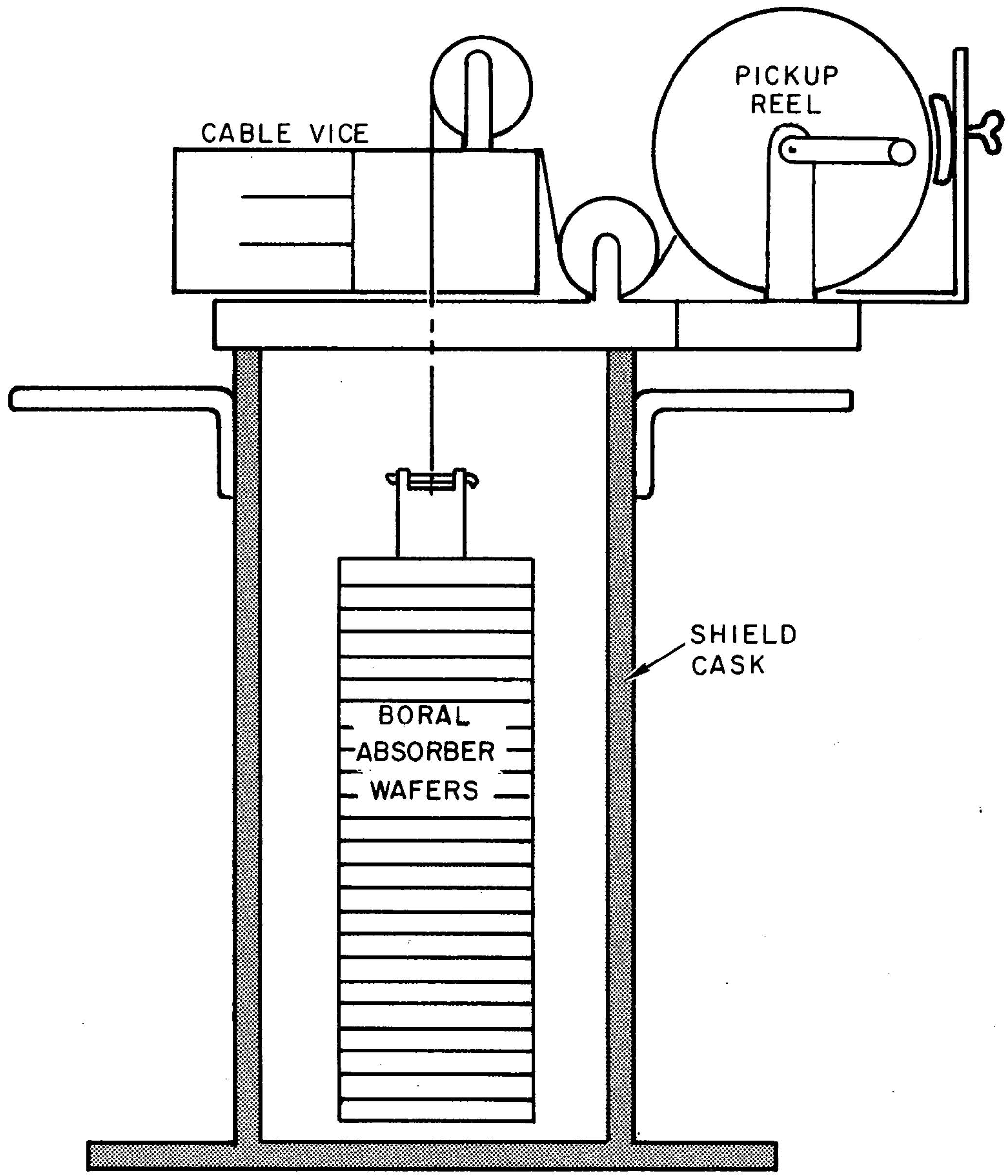


Figure IX-4. Neutron Absorber Suspension Assembly Positioned over the Shield Cask

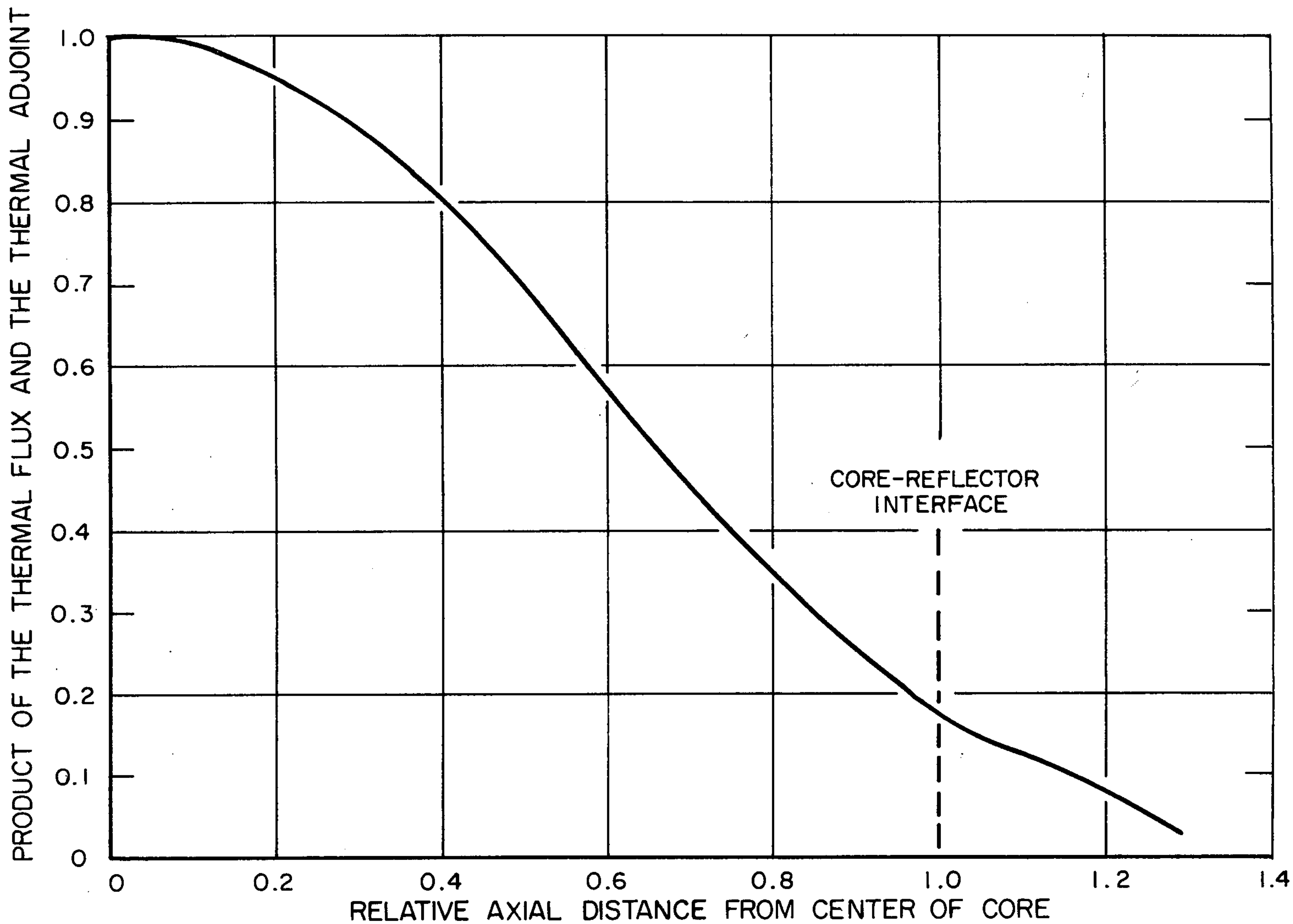
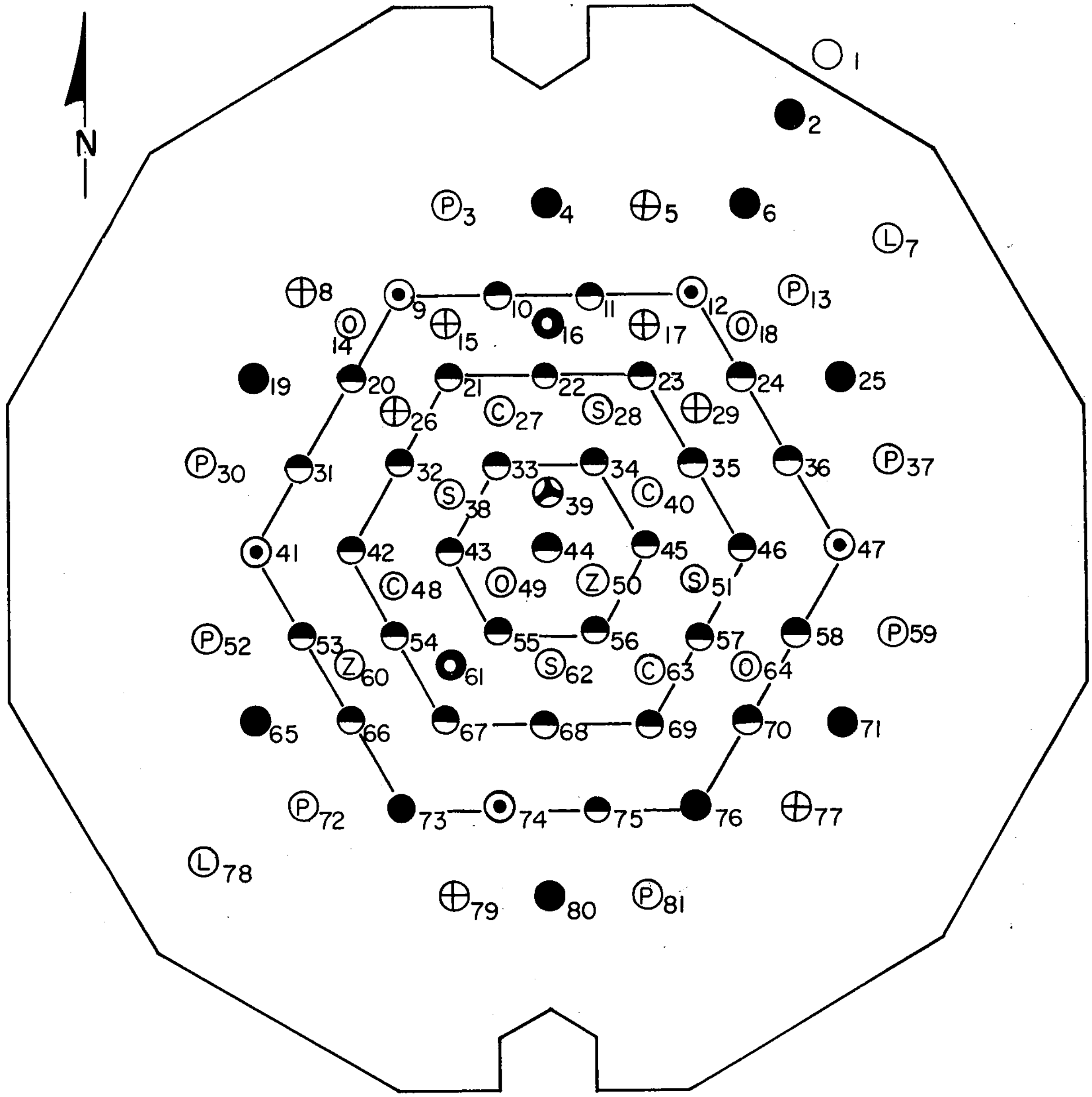


Figure IX-5. Product of the Thermal Flux and Thermal Adjoint as a Function of Axial Position



LEGEND:

- FUEL
- POOL HEATER
- SAFETY ROD
- SHIM ROD
- CENTER CHANNEL DUMMY
- Be PROBE
- NEUTRON SOURCE
- FUEL OR DUMMY
- BLIND PLUGS
- CORNER CHANNEL DUMMY
- SODIUM LEVEL INDICATOR
- ZIRCALOY-2 THIMBLE

Figure IX-6. Core Loading for Experiment

X

ISOTHERMAL TEMPERATURE COEFFICIENT OF REACTIVITY

By

R. A. LEWIS
S. F. BURTON

CONTENTS

TABLE

FIGURES

OBJECTIVE

The objective of this experiment is to measure the "isothermal" temperature coefficient of reactivity of the SRE with an operational Th-7.6 wt-%U loading.

PURPOSE

Experimental information about the temperature coefficients of reactivity in the SRE must be obtained for two reasons: first, to assist in reactor temperature stability calculations, and second, to provide data by which the reactivity of the core may be predicted for various reactor operating conditions. The isothermal temperature coefficient is also required in order to permit the separation of the more significant fuel temperature coefficient from experimental data concerning the combined effect of moderator, fuel, and coolant.

METHOD

The isothermal temperature coefficient will be measured over the temperature range from 300°F to 750°F. The lower temperature limit is chosen to be above the sodium melting point and below the normal reactor inlet temperature during operation. The upper temperature limit is set by thermal stress limits in the reactor inlet side of the main primary coolant loop. In this experiment, "isothermal" is defined as the core condition at Power level "A," constant reactor inlet and outlet temperatures, and constant control rod positions. Power level "A" is defined in Experiment III and is approximately six decades below full power.

The reactor core temperature will be changed in nine 50°F steps. At each step, the reactivity of the core relative to the 300°F critical condition will be measured using period measurements. The core temperature changes will be accomplished by eight 10-kw special pool heaters.

A shim rod configuration for which the reactivity of the reactor is known will be established for the 300°F isothermal condition by withdrawing shim rod 3 enough to obtain a positive period of about 300 seconds. The reactivity corresponding to the measured period will be computed and recorded with the position of shim rod 3. The reactor will then be raised to an isothermal condition at 350°F, using the line heaters and the special pool heaters in the sodium pool. When the reactor has reached temperature equilibrium, shim rod 3 will be withdrawn to the position which resulted in the 300-second period at 300°F. The resulting period will be measured and the reactivity calculated. The change in reactivity due to the temperature change will then be the difference in the two reactivities computed for the two withdrawals of shim rod 3 at the two different temperatures. The ratio of change in reactivity ($\Delta\rho$) to the change in temperature (ΔT) is the average temperature coefficient of reactivity for that particular temperature interval.

The above general method will be followed throughout this experiment as the reactor isothermal temperature is raised in 50°F steps from 300°F to 750°F. However, due to the expected magnitude of the total reactivity change over the temperature range of interest and the resulting excessively short periods which would result if shim rod 3 were withdrawn all the way to the position which will give a 300-sec period at the 300°F isothermal condition, the method described above must be modified at the higher temperatures. Therefore, a series of overlapping period measurements will be used in order to obtain the temperature coefficient of reactivity for the specified temperature range. Table X-1 (located at the end of subsection IV, "Subprocedures") shows the measurements to be made and the periods which are expected. This table is based on the estimate of the temperature coefficient given in the Hazards Summary.*

PROCEDURE

I. PHYSICAL SETUP AND INSTRUMENTATION

1. (O) The reactor will initially be subcritical with all shim rods inserted. Hold the flow in the main primary loop at 1000 gpm on the control room instrumentation. SET THE SODIUM LEVEL AT 115"

2. (O) If not already accomplished, install the eight 10-kw 240-volt special pool heaters in R-3, R-13, R-30, R-59, R-72, R-37, R-52, and R-81 (see Figure II-1). Each special pool heater consists of two 5-kw 240-volt heaters;

*"Hazards Summary for Thorium-Uranium Fuel in the SRE," NAA-SR-3175 (Revised).

thus, there are 16 separate pairs of heater connections. Each of the 16 heater loops may be connected to 240 volts or the two heaters in each unit may be connected in series across 480 volts.

3. (O) Provide one of the eight special pool heaters mentioned in Step 2 with a Variac control.

4. (O) Each of the following line heaters will be individually provided with an on-off switch and connected across a 240-volt line (all line heaters are 1/2 kw except as noted).

Main Primary

Line 101: ER-38, 39, 40, 41, and 42
Line 102: ER-36, 37, and 5 (120 volt, 1/4 kw).
Line 103: ER-27, 28, 29, 30, 31, 32, 33, 34, and 35.

5. (E) Using the technique discussed in Experiment III, set up the Sanborn Recorders to record:

1) Reactor inlet temperature.
2) Reactor exit temperature.
3) Two Na Channel exit temperatures.

} PUT ON ONE 4 PEN SANBORN

4) Two Be probe thermocouple temperatures. } PUT ON 2 PEN SANBOR

6. (O) If they are not already operating, set up the television systems to display the Veeder counters on screens in the control room area.

7. (O) Disconnect the Flux-Temperature Recorder-Controller from the ionization chamber and connect it to the Beckman electrometer channel in preparation for the use of the flux controller at power levels in the first decade of the log N chart.

8. (E) The instrumentation for period measurements should be set up as previously used (see Figure X-1).

II. INITIAL CONDITIONS

9. (O) Set the main primary system flow rate at 1000 ± 10 gpm as indicated on the control room instrumentation. Hold this flow as constant as possible throughout this experiment.

10. (O) Shut off flow in auxiliary primary system.

11. (O) Either drain the main secondary system or maintain the secondary temperature so that no heat is withdrawn from the main primary system during this test.

12. (O) The reactor startup source must be in the reactor.

13. (O) Bring the reactor power up to point "A" as defined in Experiment III.

3000 V.U. 14. (O) Adjust the shim rod configuration such that shim rod 3 is at about ~~5000 V.U.~~, shim rods 1, 2, and 4 are at a common level (within ±40 V.U.), and the reactor power is at point "A." The reactor should be on manual control. Record the position of shim rods 1, 2, and 4. Do not move shim rods 1, 2, and 4 during this experiment except for safety purposes.

III. REACTIVITY MEASUREMENTS

In the following steps, twenty-five period measurements will be made. These are summarized in Table X-1. The Subprocedures A, B, C, and D referred to below are detailed in the following section (IV).

15. (E) Begin continuous monitoring of the temperatures listed in Step 5. It is not necessary to have the Sanborn Recorder Charts moving at all times.

300

16. (O,E) Adjust the core to an isothermal condition at N = 300 ± 10°F according to Subprocedure B. (N refers to nominal core temperature at each temperature step.)

17. (O,E) Determine X(300) according to Subprocedure C. In general, the notation X(N) refers to the position of shim rod 3, at the nominal core temperature N, which results in a period at approximately 300 seconds.

350

18. (O,E) Adjust the core to an isothermal condition at N = 350 ± 10°F according to Subprocedure B.

19. (O, E) Determine X(350) according to Subprocedure C.

20. (O, E) Adjust the power to the line heaters as necessary to maintain N.

21. (O, E) Pull shim rod 3 to X(300) according to Subprocedure D.*

<u>400</u>

22. (O, E) Adjust the core to an isothermal condition at N = 400 ± 10°F according to subprocedure B.

23. (O, E) Determine X(400) according to Subprocedure C.

24. (O, E) Repeat Step 20.

25. (O, E) Pull shim rod 3 to X(350) according to Subprocedure D.

<u>450</u>

26. (O, E) Adjust the core to an isothermal condition at N = 450 ± 10°F according to Subprocedure B.

27. (O, E) Determine X(450) according to Subprocedure C.

28. (O, E) Repeat Step 20.

29. (O, E) Pull shim rod 3 to X(400) according to Subprocedure D.

30. (O, E) Repeat Step 20.

31. (O, E) Pull shim rod 3 to X(350) according to Subprocedure D.

32. (O, E) Adjust the core to an isothermal condition at N = 500 ± 10°F according to Subprocedure B.

33. (O, E) Determine X(500) according to Subprocedure C.

34. (O, E) Repeat Step 20.

---

*Note to the Experimental Unit Engineer: In order to obtain the maximum amount of information from this experiment, it is desirable to proceed to pull shim rod 3 back to the values of X(N) which are as far to the left in each horizontal row of Table X-1 as is possible without getting a period shorter than 30 seconds. If it appears that at the end of the measurements called for in this procedure, at a particular temperature step, it is possible to pull shim rod 3 to a lower X(N) than called for, without a period shorter than 30 seconds resulting, then perform these additional measurements according to Subprocedure D.

35. (O, E) Pull shim rod 3 to X(450) according to Subprocedure D.

36. (O, E) Repeat Step 20.

37. (O, E) Pull shim rod 3 to X(400) according to Subprocedure D.

550

38. (O, E) Adjust the core to an isothermal condition at N = 550 ± 10°F according to Subprocedure B.

39. (O, E) Determine X(550) according to Subprocedure C.

40. (O, E) Repeat Step 20.

41. (O, E) Pull shim rod 3 to X(500) according to Subprocedure D.

42. (O, E) Repeat Step 20.

43. (O, E) Pull shim rod 3 to X(450) according to Subprocedure D.

600

44. (O, E) Adjust the core to an isothermal condition at N = 600 ± 10°F according to Subprocedure B.

45. (O, E) Determine X(600) according to Subprocedure C.

46. (O, E) Repeat Step 20.

47. (O, E) Pull shim rod 3 to X(550) according to Subprocedure D.

48. (O, E) Repeat Step 20.

49. (O, E) Pull shim rod 3 to X(500) according to Subprocedure D.

650

50. (O, E) Adjust the core to an isothermal condition at N = 650 ± 10°F according to Subprocedure B.

51. (O, E) Determine X(650) according to Subprocedure C.

52. (O, E) Repeat Step 20.

53. (O, E) Pull shim rod 3 to X(600) according to Subprocedure D.

54. (O, E) Repeat Step 20.

55. (O, E) Pull shim rod 3 to X(550) according to Subprocedure D.

700

56. (O, E) Adjust the core to an isothermal condition at N = 700 ± 10°F according to Subprocedure B.

57. (O, E) Determine X(700) according to Subprocedure C.

58. (O, E) Repeat Step 20.

59. (O, E) Pull shim rod 3 to X(650) according to Subprocedure D.

60. (O, E) Repeat Step 20.

61. (O, E) Pull shim rod 3 to X(600) according to Subprocedure D.

62. (O, E) Repeat Step 20.

63. (O, E) Pull shim rod 3 to X(550) according to Subprocedure D.

750

64. (O, E) Adjust the core to an isothermal condition at N = 750 ± 10°F according to Subprocedure B.

65. (O, E) Pull shim rod 3 to X(700) according to Subprocedure D.

66. (O, E) Repeat Step 20.

67. (O, E) Pull shim rod 3 to X(650) according to Subprocedure D.

68. (O, E) Repeat Step 20.

69. (O, E) Pull shim rod 3 to X(600) according to Subprocedure D.

70. (O, E) Repeat Step 20.

71. (O, E) Pull shim rod 3 to X(550) according to Subprocedure D.

IV. SUBPROCEDURES

Subprocedure A. Procedure for Core Temperature Change

In the course of this experiment, several core temperature changes are called for. Also, constant core temperature is called for in several instances. The large-capacity special pool heaters are designed to be used to change the temperature level of the core; at full heater power, a core temperature change of 5 to 5-1/2°F per hour is expected. Since the main primary line heaters are capable of sustaining the core temperature at any level up to 750°F, they will be relied upon to hold steady core temperatures. (In this experiment, "core temperature" means the average of the reactor inlet and outlet temperatures as read on the Sanborn Recorders.)

The procedure for changing core temperature will be:

1. (O) The reactor may remain critical or be shut down during temperature level changes. In the case the reactor is shut down, power level "A" must be established and held for the last hour of the temperature change. The positions of shim rods 1, 2, and 4 must be exactly reproduced, according to the Veeder counters, as they were before the shutdown.

2. (O) Turn on all pool and line heaters.

3. (E, O) When the core temperature reaches N ± 10°F, turn off the special pool heaters.

4. (O) Level out the core temperature by adjusting the number of main primary line heaters connected.

<u>Subprocedure B. Procedure for Establishment of an Isothermal Condition</u>

1. (O) Using Subprocedure A, bring the reactor core temperature to N ± 10°F. N will be 300, 350, 400, 450, 500, 550, 600, 650, 700, or 750°F, as required.

2. (O) With the reactor on manual control, set the reactor power at point "A" and hold it as steady as possible. Control only with shim rod 3; do not move shim rods 1, 2, and 4. The positions of shim rods 1, 2, and 4 must be exactly the same as they were before the temperature change.

3. (O, E) Turn off all special pool heaters and adjust the power to the line heaters until the reactor inlet and outlet temperatures are constant as determined on the Sanborn Recorders.

4. (O) Place shim rod 3 on automatic flux control.

5. (E) Wait until shim rod 3 shows no apparent drift on automatic control.

Subprocedure C. Determination of X(N)'s

Subprocedure B must have been performed at temperature N. X(N) is the position of shim rod 3 at the temperature N ± 10°F which will place the reactor on a 300 ± 25 second positive period. If necessary, adjust the power to the line heaters during this subprocedure to maintain constant temperature.

1. (O) Place the reactor on manual control. Hold a constant flux level at point "A" for 20 minutes, controlling only with shim rod 3.

2. (E) Record the reactor inlet and outlet temperatures from the Sanborn Recorders. Record the position of shim rod 3. Record the positions of shim rods 1, 2, and 4.

3. (E) Set the Beckman-Berkeley system to count for 20 out of 23 seconds and set the Systron System to count for 20 out of 20.5 seconds.

4. (O) Pull shim rod 3 for a 300 ± 25 second period. This period must be established before the power has increased by 1/2 decade. If it is not, return to power "A" - wait 20 minutes - and try again. Do not move shim rods 1, 2, and 4.

5. (E, O) When shim rod 3 stops, immediately turn on the printers. DO NOT move shim rod 3 after the printers are turned on. Record the position of shim rod 3; this is X(N).

6. (O, E) When the flux reaches point "T," IMMEDIATELY insert shim rod 3 and reduce the flux to point "A." Turn off printers. Adjust to constant flux at point "A," controlling only with shim rod 3. Point "T" is defined in Experiment III, and is about three decades below full power.

7. (E) Record the reactor inlet and outlet temperatures from the Sanborn Recorders.

8. (E) Analyze the data as described in the Analysis Section.

Subprocedure D. Temperature Coefficient Measurement

1. (O) Place the reactor on manual control. Hold the flux constant at point "A" for 20 minutes, controlling only with shim rod 3.

2. (E) Record reactor inlet and outlet temperatures from the Sanborn Recorders. Record the position of shim rod 3. Record the position of shim rods 1, 2, and 4.

3. (E) If the period predicted by Table X-1 is between 70 and 120 seconds, set the Beckman System to count for 10 out of 13 seconds and the Systron System to count for 10 out of 10.5 seconds. If the period predicted by Table X-1 is less than 70 seconds, set the Beckman System to count for 5 out of 8 seconds and the Systron System to count for 5 out of 5.5 seconds.

4. (O) Pull shim rod 3 to X(N). DO NOT move shim rods 1, 2, and 4. All rod motion must stop before the flux has risen by 1/2 decade above "A." If X(N) has not been established within ± 1 V.U. by that time, insert shim rod 3 and return to point "A," controlling with shim rod 3. Repeat Step 1.

5. (O, E) If the resultant asymptotic period is less than 30 seconds, immediately reinsert shim rod 3 and reduce the flux to point "A." Proceed to the next step in the main procedure. Notify R. W. Woodruff.

6. (E, O) When shim rod 3 stops, immediately turn on the printers. Do not move shim rod 3 after the printers are turned on. Record the position of shim rod 3 (this should be X(N)).

7. (O, E) When the flux reaches point T, IMMEDIATELY insert shim rod 3 and reduce the flux to point "A." Turn off printers. Adjust to constant flux at point "A," controlling only with shim rod 3.

8. (E) Record the reactor inlet and outlet temperatures from the Sanborn Recorders.

9. (E) Analyze the data as described in the Analysis Section.

TABLE X-1

SUMMARY OF PERIOD MEASUREMENTS FOR ISOTHERMAL TEMPERATURE COEFFICIENT MEASUREMENTS

Temperature °F	Period in Seconds								
	X(300)	X(350)	X(400)	X(450)	X(500)	X(550)	X(600)	X(650)	X(700)
300	300								
350	62	300							
400	26	67	300						
450	14	29	70	300					
500		16	32	75	300				
550			18	36	85	300			
600				21	42	100	300		
650					28	52	120	300	
700					21	36	69	145	300
750					17	30	52	100	195

The periods listed in the table are those which are predicted to result when shim rod 3 is withdrawn from its constant flux position for the temperatures in the left hand column to the shim rod 3 positions in the top row. The shim rod 3 positions in the top row refer to positions of shim rod 3 which will give an approximately 300-second positive period at the subcripted temperatures when the other three shim rods are at the common position which was set in Step 14. The calculated periods are based on the assumption of a temperature coefficient 50% larger than that quoted in NAA-SR-3175 (Revised). The underlined periods indicate measurements which will be made during this experiment.

SAMPLE DATA RECORD

RUN NUMBER	1 FUNCTION X(N) OR PULL TO X(N)	2 SCALER-PRINTER	3 RESOLUTION TIME	4 COUNTING TIME	5 CYCLE TIME	6 SHIM-1 POSITION (V.U.)	7 SHIM-2 POSITION (V.U.)	8 SHIM-4 POSITION (V.U.)	9 SHIM-3 POSITION CONSTANT FLUX AT POINT "A" (V.U.)	10 TIME BEFORE MOVING SHIM-3 (T_1)	11 REACTOR INLET TEMP. AT T_1 (°F)	12 REACTOR OUTLET TEMP. AT T_1 (°F)	13 AVERAGE CORE TEMP. AT T_1 (°F)	14 SHIM-3 POSITION ~300 SEC. PERIOD X(N) (V.U.)	15 POSITION TO WHICH SHIM-3 MOVED (V.U.)	16 TIME AFTER PRINTER TURNED OFF (T_2)	17 REACTOR INLET TEMP. AT T_2 (°F)	18 REACTOR OUTLET TEMP. AT T_2 (°F)	19 AVERAGE CORE TEMP. AT T_2 (°F)
1	X(300)																		
2	X(350)																		
3	P TO X(300)																		
4	X(400)																		
5	P TO X(350)																		
6	ETC																		
7																			
8																			
9																			
10																			

ANALYSIS OF DATA

A. ANALYSIS OF PERIOD DATA

Analyze the data from each period run as follows:

1. Obtain the waiting time from the plot prepared in Experiment III and eliminate the data points which fall within it.

2. Calculate the count rate for each point by dividing the count by the counting time. Correct the data points for the system resolution time by the equation

$$\dot{n} = \frac{\dot{m}}{1 - \dot{m}\tau}, \qquad \ldots (1)$$

where

$\dot{n}$ = true count rate,

$\dot{m}$ = measured count rate,

τ = system resolution time.

3. Plot the corrected count rate vs time data on semilog paper.

4. Draw the best fit straight line through the data.

5. Calculate the period by dividing the time it takes the straight line to traverse 2 decades by 4.605. If the period is so long that a 2-decade rise does not occur within the range of the graph paper, then compute the period by extending the straight line until it completely traverses the graph paper. Take the two extreme points on the line; call the count rates C_1 and C_2, and the respective times t_1 and t_2. Calculate the period by the relation

$$\text{Period} = \frac{t_2 - t_1}{\ln C_2 - \ln C_1}, \qquad \ldots (2)$$

where ln is $\log_e$.

6. Convert the period to reactivity by use of the graph of reactivity vs period included in the SRE Ready Reference Manual. Convert the reactivity thus found to cents by multiplying the reactivity obtained from the graph by 1.43×10^2.

7. Submit the data to IBM analysis according to the description in Appendix E of Experiment III.

B. CALCULATION OF TEMPERATURE COEFFICIENT OF REACTIVITY

The basic plan in this experiment is to measure the change in the reactivity of the core due to "isothermal" temperature changes in nine 50°F steps. The reactivity change in each 50°F step will be measured using a period measurement as shown in Table X-1. In some cases, the reactivity change over 100, 150, and even 200°F will be measured integrally as shown in Table X-1.

At each step from 300 to 700°F, a shim configuration will be established for which the reactivity of the core is known, i.e., the X(N)'s. The reactor is then heated to a higher temperature and the previously established shim rod configuration re-established. Any difference in the reactivity of the core must then be due to the temperature effects.

1. At N°F calculate the reactivity corresponding to X(N); call this ρ (N).

2. At (N + 50)°F calculate the reactivity when X(N) is re-established; call this ρ(N + 50, N). Calculate the $\Delta\rho$ for the 50°F step by

$$\Delta\rho = \rho\,(N + 50,\ N) - \rho\,(N). \qquad \ldots(3)$$

3. Calculate the average temperature coefficient by

$$\alpha_T = \frac{\Delta\rho}{\Delta T}, \qquad \ldots(4)$$

where ΔT is the actual change in the average core temperature, i.e. about 50°F.

4. Plot the α_T computed in Step 3 at the midpoint of the temperature of the step, i.e.,

$$T = \frac{N + (N + \Delta T)}{2}. \qquad \ldots(5)$$

(See Figure X-2)

5. Plot the $\Delta\rho$ on an integral curve similar to Figure X-3 by adding it to the preceding $\Delta\rho$'s above 300°F and plotting at the temperature $(N + \Delta T)$. (see Figure X-3.)

EXPECTED RESULTS

The expected isothermal temperature coefficient and reactivity curves are shown in Figures X-2 and X-3, respectively. The solid line curve in each figure was drawn based on estimates published in NAA-SR-3175 (Revised). The dashed curves indicate the approximate range of error (± 50%). For comparison purposes, the straight line curve in Figure X-2 is the temperature coefficient obtained from the Supplement to NAA-SR-3175 (Revised).

EXPECTED CONCLUSIONS

The isothermal temperature coefficient of reactivity is expected to change from positive to negative at about the same temperature (700-800°F) as was found for the first SRE fuel loading (U^{235} - U^{238}).

APPENDIX

A. SCHEDULE

Changing temperature levels	115 hours (minimum)
Temperature leveling-off periods	10 hours
Period measurements	30 hours
Total	155 hours

Estimate: 7 days for test

B. MANPOWER REQUIREMENTS

One engineer and one technician from the Experimental Unit are minimum requirements on all shifts during test. The regular operating crew will also be needed.

C. EQUIPMENT REQUIREMENTS

2 operational fission chambers

2 scaler-timer-printer units

6 low-level Sanborn Recorder channels

1 thermocouple reference junction

D. CREDIBLE ACCIDENTS

Loss of main primary flow with full power to the special pool heaters will result in a rise of upper plenum temperature of about 5°F per minute, assuming no losses. If this occurs, the power to the special pool heaters should be cut off within 5 minutes. During the period measurements, none of the safety interlocks will be bypassed.

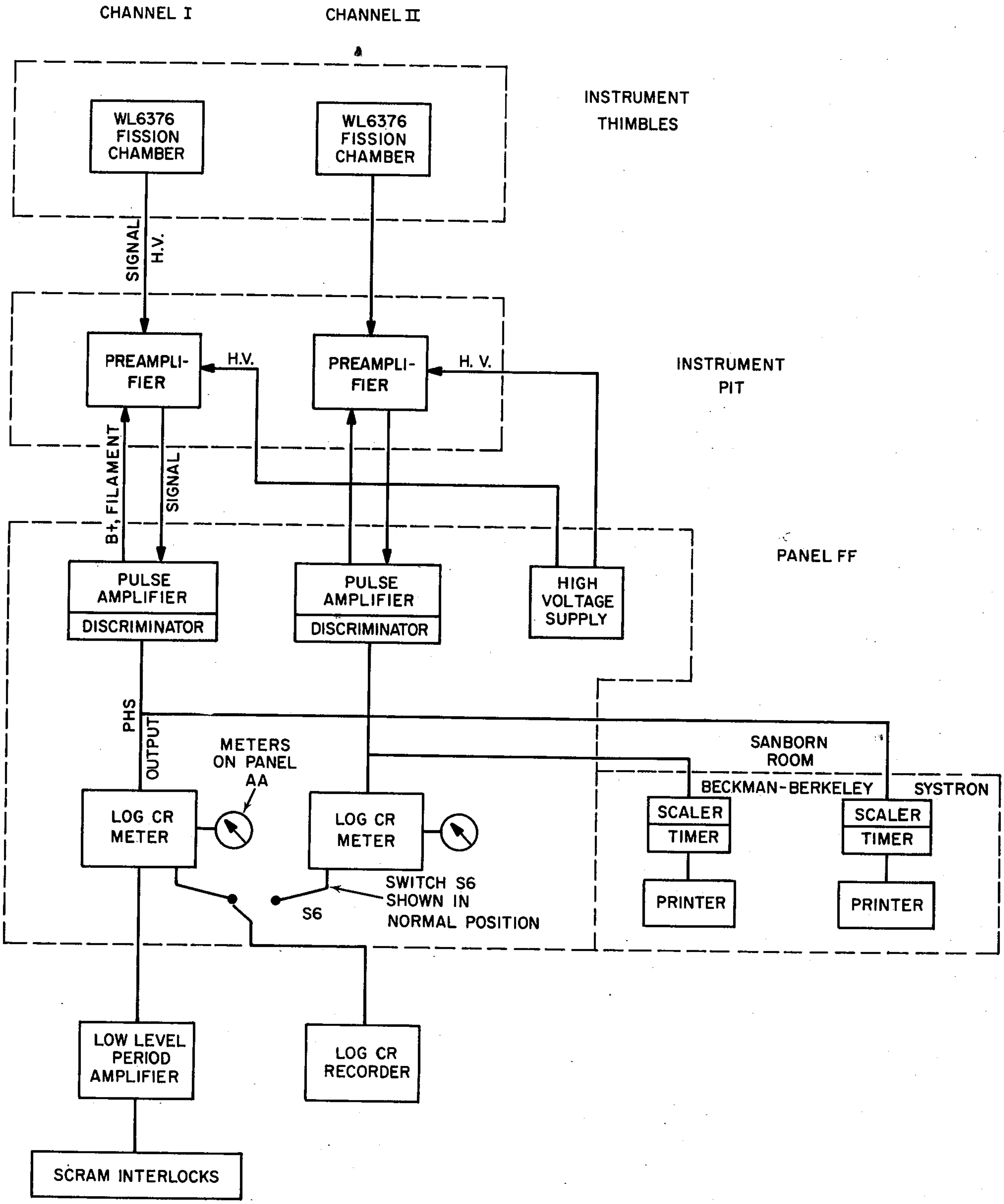


Figure X-1. Equipment for Period Measurements

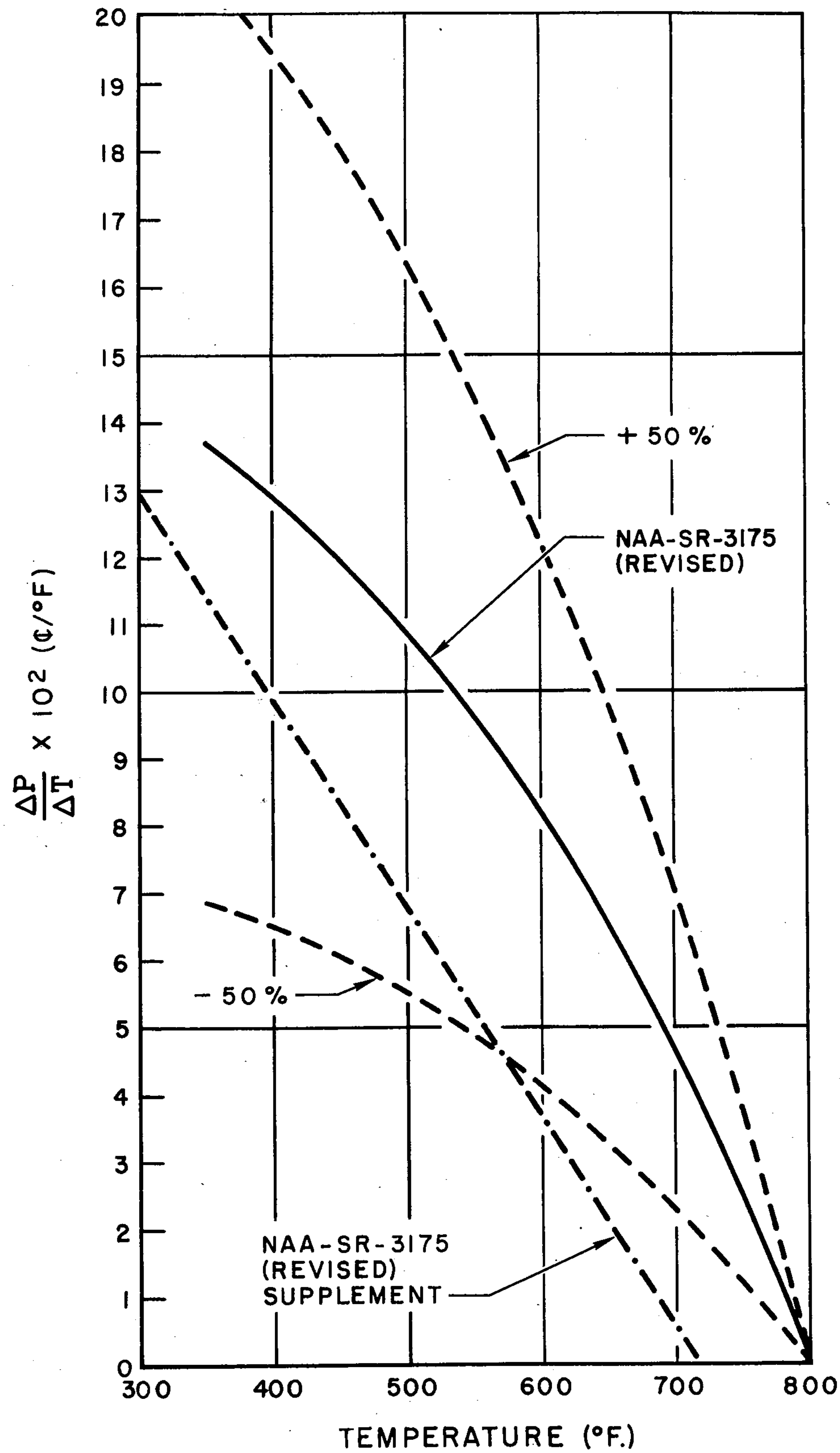


Figure X-2. Predicted Isothermal Temperature Coefficient of Reactivity $\left(\alpha_T = \frac{\partial \rho}{\partial T}\right)$

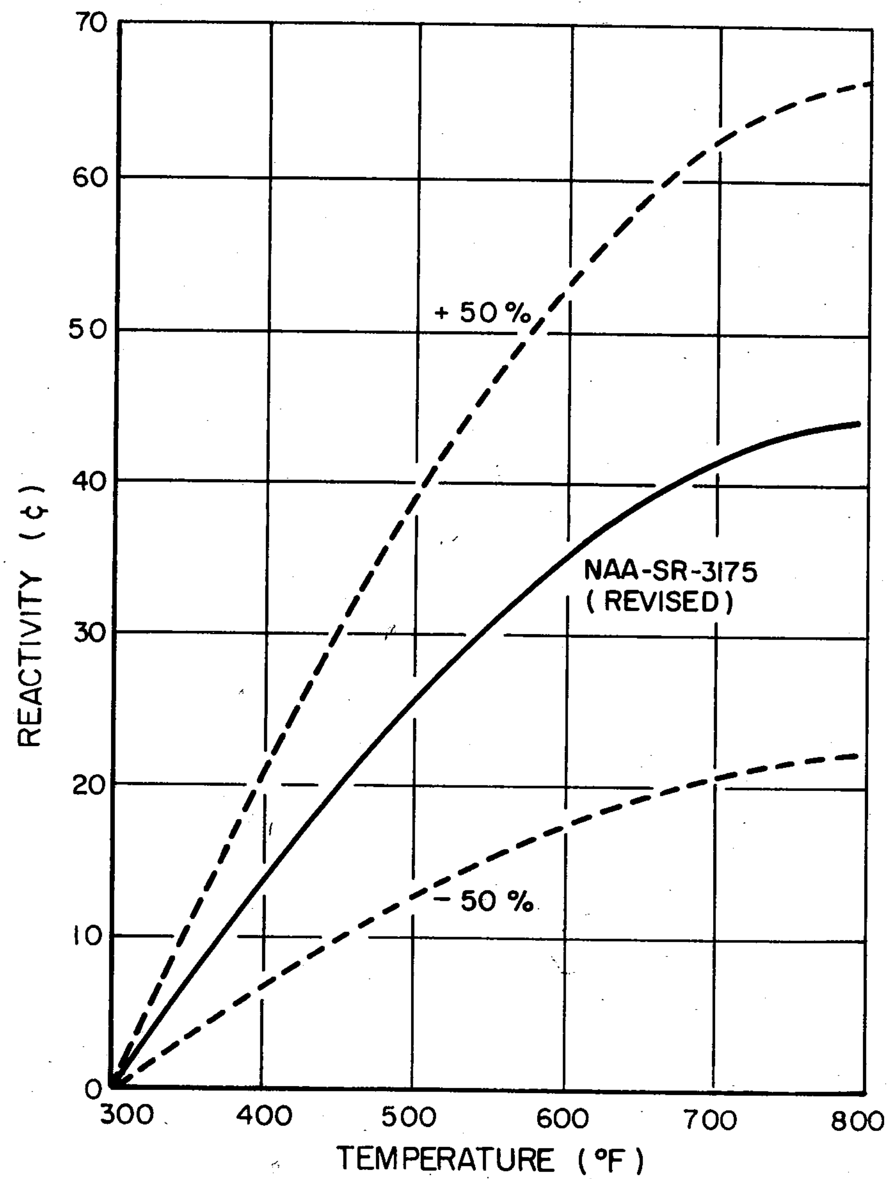


Figure X-3. Predicted Change in Reactivity During the Measurement of the Isothermal Temperature Coefficient $\left(\int_{300}^{T} \alpha_T dT\right)$

APPENDIX I.
SAFETY CHANNEL CHANGES

The special safety channels used during the ciritical loading experiment are described in detail in the procedure for the experiment. After the operational loading has been attained, the normal SRE safety channels* shown in Figure A-I-1 will be operating. The set-points for reactor scrams, setbacks, and alarms which are used during the low-power experiments are shown in Table A-I-1, and Table A-I-2 lists the reactor interlocks.

A few changes must be made to the interlocks or safety channels during some of the experiments. All of these changes are listed in Table A-I-3. In each case the system will be returned to the original condition at the end of the experiment. All of the changes are small, and none will compromise the safety of the reactor.

*R. J. Hall, "SRE Instrumentation and Control," NAA-SR-Memo-1639.

TABLE A-I-1

SETPOINTS FOR REACTOR SCRAMS, SETBACKS, AND ALARMS DURING THE LOWER-POWER EXPERIMENTS

	Scram	Setback	Alarm
1. Manual		X	
2. Electrical power failure	After 2 sec delay		
3. Reactor period (high-level period channels)	< 5 sec	< 10 sec	< 20 sec
4. Reactor period[1] (low-level channels)	< 4 sec [1]		
5. Neutron level (high-level flux channels)	> 0.8% full power (160 kw)	> 0.75% (150 kw)	> 0.6% (120 kw)
6. Main primary sodium flow	< 900 gpm		< 950 gpm
7. Fuel channel exit temperature	< 390°F		

(1) This circuit will be used only if period measurements must be started below the range of the high-level period instrumentation.

TABLE A-I-2

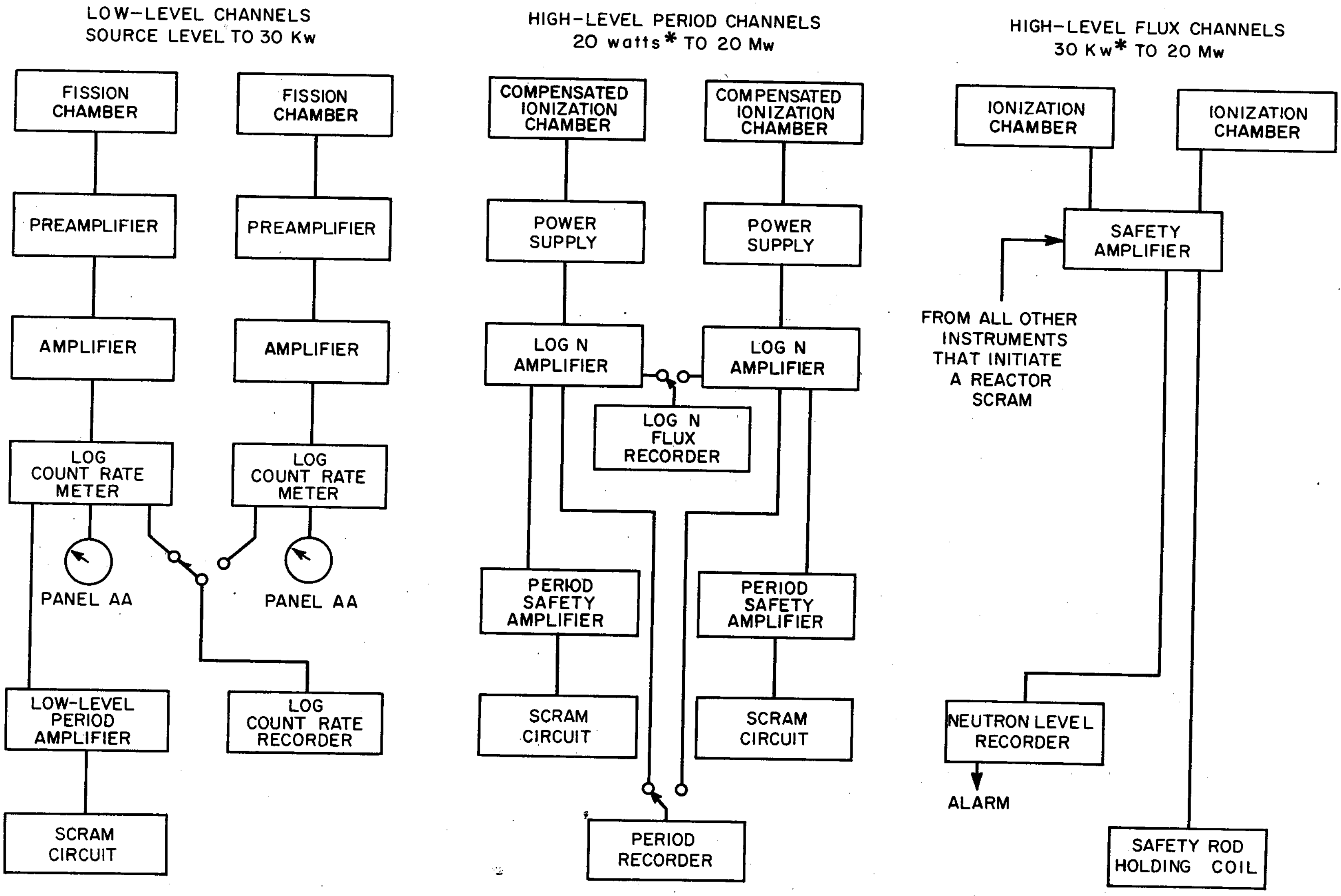
REACTOR INTERLOCKS

1. No safety rod can be raised unless all shim rods are completely inserted.
2. No safety rod can be raised unless the count rate meter indicates source neutron background.
3. No shim rod can be raised unless all safety rods are completely withdrawn.
4. No shim or safety rod can be raised if any condition prevails which would cause a reactor scram.

TABLE A-I-3

CHANGES IN INTERLOCKS OR SAFETY CHANNELS DURING THE LOW-POWER EXPERIMENTS

Experiment	Changes from Table A-I-1 or A-I-2	Remarks
Setup and test of the period and temperature measuring equipment	The log count rate recorder will be set to scram the reactor at less than 1 count/sec during the source removal test.	The change will be made by the Operations Unit.
Shim rod calibrations by period measurements	Interlocks 1 and 3 will be bypassed during the calibration of the safety rods.	The change will be made by the Operations Unit.
Shim rod calibration with the reactor oscillator	Interlock 1 will be bypassed during the experiment.	The change will be made by the Operations Unit.
Measurement of the radial statistical weight	None	
Measurement of the axial flux traverse	None	
Measurement of the reactor transfer function with the reactor oscillator	None	
Measurement of the amplitude of the reactor transfer function in the high frequency region by noise analysis techniques	None	
Measurement of the axial statistical weight	None	
Measurement of the isothermal temperature coefficient of reactivity	Set point for fuel channel exit temperature scram will be adjusted before each temperature increase. The setpoint will be 50°F above the new isothermal temperature.	Changes will be made by the Operations Unit.



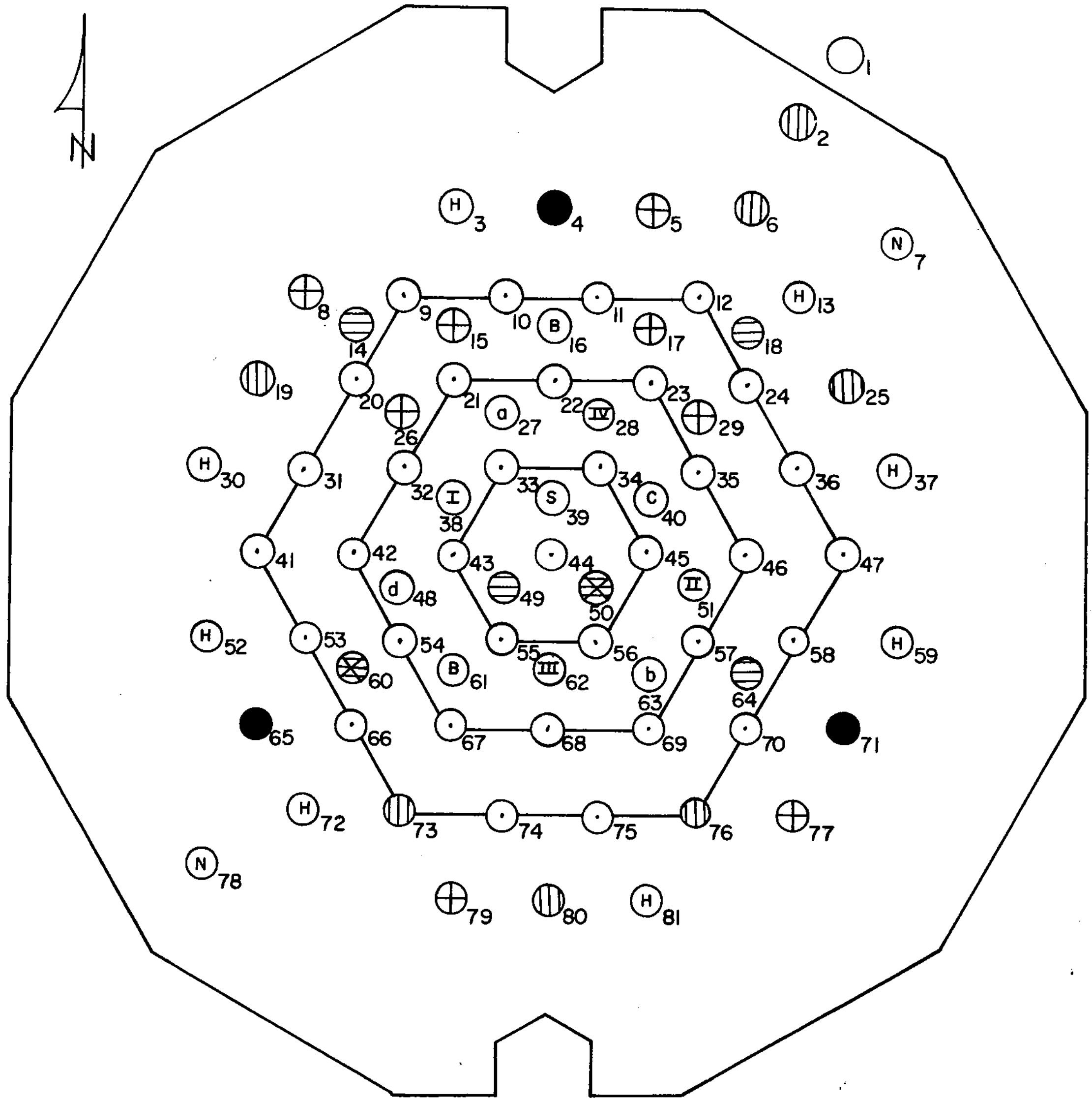
*IONIZATION CHAMBERS AT THE BOTTOMS OF THE THIMBLES.

Figure A-I-1. SRE Nuclear Safety Channels

APPENDIX II.
CORE LOADING CHANGES

Figure A-II-1 and Table A-II-1 show the SRE core loading configuration during the low-power physics experiments following the Critical Loading Experiment. Figure A-II-1 shows the expected operational core configuration at the completion of the Critical Loading Experiment. Due to the uncertainty in the criticality calculations, one or more of Channels 74, 41, 9, 12, and 47 may have center dummy elements in them instead of fuel elements as shown.

In the experiments which follow the Critical Loading Experiment, component changes are made in only 12 channels. Table A-II-1 gives the experiment and step number in the procedure where these changes occur, in addition to the configuration after each change. Therefore, using Figure A-II-1 and Table A-II-1, the core loading can be ascertained at any time during the low-power experiments.



LEGEND :

- FUEL ELEMENT
- SHIM ROD
- SAFETY ROD
- SOURCE
- BLIND PLUG
- CENTER DUMMY
- CORNER DUMMY
- FISSION CHAMBER IN SS THIMBLE
- POOL HEATER
- NA LEVEL PROBE
- BE TEMP. PROBE
- THERMOPILE IN GRAPHITE FILLED ZIRCALOY-2 THIMBLE.
- SODIUM

Figure A-II-1. Operational Core Configuration Following Experiment II

CHANNEL	OPERATIONAL LOADING	PERIOD AND TEMP. INSTRUMENTATION	RADIAL STATISTICAL WEIGHT												THERMAL NEUTRON FLUX MEASUREMENTS					
		Step 14	Step 10	Step 15a	Step 15b	Step 15c	Step 15d	Step 15e	Step 16	Step 18	Step 19	Step 21	Step 23	Step	Step 14	Step 22	Step 29	Step 38	Step 39a	Step 39b
4	FISSION CHAMBER IN SS THIMBLE	CENTER DUMMY																		
41	SU-22-41							STANDARD DUMMY FUEL ASSEMBLY	STANDARD ENRICHED URANIUM FUEL ASSEMBLY	SU-22-41										
42	SU-22-8					STANDARD DUMMY FUEL ASSEMBLY	SU-22-8													
44	SU-22-11		STANDARD DUMMY FUEL ASSEMBLY	SU-22-11																
49	CORNER DUMMY																			
50	THERMOPILE IN ZIRCALOY THIMBLE													ZIRCALOY THIMBLE	ZIRCALOY THIMBLE WITH SS WIRE	ZIRCALOY THIMBLE	ZIRCALOY THIMBLE WITH COBALT WIRE	ZIRCALOY THIMBLE		
53	SU-22-30						STANDARD DUMMY FUEL ASSEMBLY	SU-22-30												
54	SU-22-20				STANDARD DUMMY FUEL ASSEMBLY	SU-22-20														
55	SU-22-39			STANDARD DUMMY FUEL ASSEMBLY	SU-22-39						STANDARD ENRICHED URANIUM FUEL ASSEMBLY	SODIUM	SU-22-39							
60	THERMOPILE IN ZIRCALOY THIMBLE													ZIRCALOY THIMBLE					ZIRCALOY THIMBLE WITH COBALT WIRE	ZIRCALOY THIMBLE
65	FISSION CHAMBER IN SS THIMBLE	CENTER DUMMY																		
71	FISSION CHAMBER IN SS THIMBLE	CENTER DUMMY																		

Table A-II-1. Changes in Core Configuration During Low Power Physics Experiments
(Sheet 1 of 2)

THERMAL NEUTRON FLUX MEASUREMENTS												REACTOR OSCILLATOR MEASUREMENTS II. TRANSFER FUNCTION MEASUREMENT		AXIAL STATISTICAL WEIGHT					
Step 40a	Step 40b	Step 40c	Step 40d	Step 41a	Step 41b	Step 41c	Step 41d	Step 41e	Step 46	Step 58	Step 59	Step A-4	Step F-3	Step 1	Step 11	Step 22	Step 26	Step 30	Step 31
												SPECIAL THIMBLE WITH OSCILLATOR ROTOR & STATOR	CORNER DUMMY						
ZIRCALOY THIMBLE. GOLD WIRE WITH 4" CADMIUM SPACING	ZIRCALOY THIMBLE			ZIRCALOY THIMBLE. GOLD WIRE WITH 6" CADMIUM SPACING	ZIRCALOY THIMBLE. GOLD WIRE WITH 8" CADMIUM SPACING	ZIRCALOY THIMBLE. GOLD WIRE WITH 10" CADMIUM SPACING	ZIRCALOY THIMBLE. GOLD WIRE WITH 12" CADMIUM SPACING	ZIRCALOY THIMBLE		ZIRCALOY THIMBLE, THERMOPILE	ZIRCALOY THIMBLE			EMPTY ZIRCALOY THIMBLE	ZIRCALOY THIMBLE WITH BORAL POISON	ZIRCALOY THIMBLE	CORNER DUMMY		
		ZIRCALOY THIMBLE. GOLD WIRE WITH 4" CADMIUM SPACING	ZIRCALOY THIMBLE						ZIRCALOY THIMBLE. THERMOPILE		ZIRCALOY THIMBLE			CORNER DUMMY			EMPTY ZIRCALOY THIMBLE	ZIRCALOY THIMBLE WITH BORAL POISON	CORNER DUMMY

Table A-II-1. Changes in Core Configuration During Low Power Physics Experiments (Sheet 2 of 2)