NSCR POST DAMAGE PULSE TEST PROGRAM

For

A FULL FLIP TRIGA CORE

January 1983

RSB Review and Approval: R. L. Watson
R. L. Watson, Acting Chairman
Reactor Safety Board

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Date

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I. Introduction

Pulsing operations of the Nuclear Science Center Reactor (NSCR) were terminated in September 1976 following the discovery of three damaged fuel elements. A detailed operating history of NSCR cores since the discovery is provided in Appendix A. Based on the completion and approval of a final fuel element damage report[1] and submittal of material to the USNRC, dated 16 April 1982, a three phase post damage pulse test program has been developed for the resumption of pulsing of the NSCR. A full FLIP core loading designated as Core VIII has been selected for the pulse test program (see Figure 1).

In this program peak core temperature values will be determined for stepwise increased pulse reactivity insertions. These values will be obtained by applying calculated peaking factors to observed fuel thermocouple temperatures, and, in addition, core pulse energy will be determined by the foil activation method for a given reactivity insertion. The pulse data obtained will be extrapolated to determine the maximum allowable reactivity insertion to produce a peak core temperature of 830^{o}C and to predict the maximum core temperature for the accidental insertion of the full worth of the transient rod. It should also be noted that in this program requirements have been established for the periodic inspection of fuel elements expected to experience the highest core temperatures. The program will progress by phases, and local review and approval by the Reactor Safety Board will be completed prior to entering each phase.

II. Objectives

The pulse test program for the resumption of pulsing of the NSCR is designed to meet the following objectives:

(1) Assure that the maximum core temperature will not exceed 830^{o}C (1526^{o}F) during pulsing operation.

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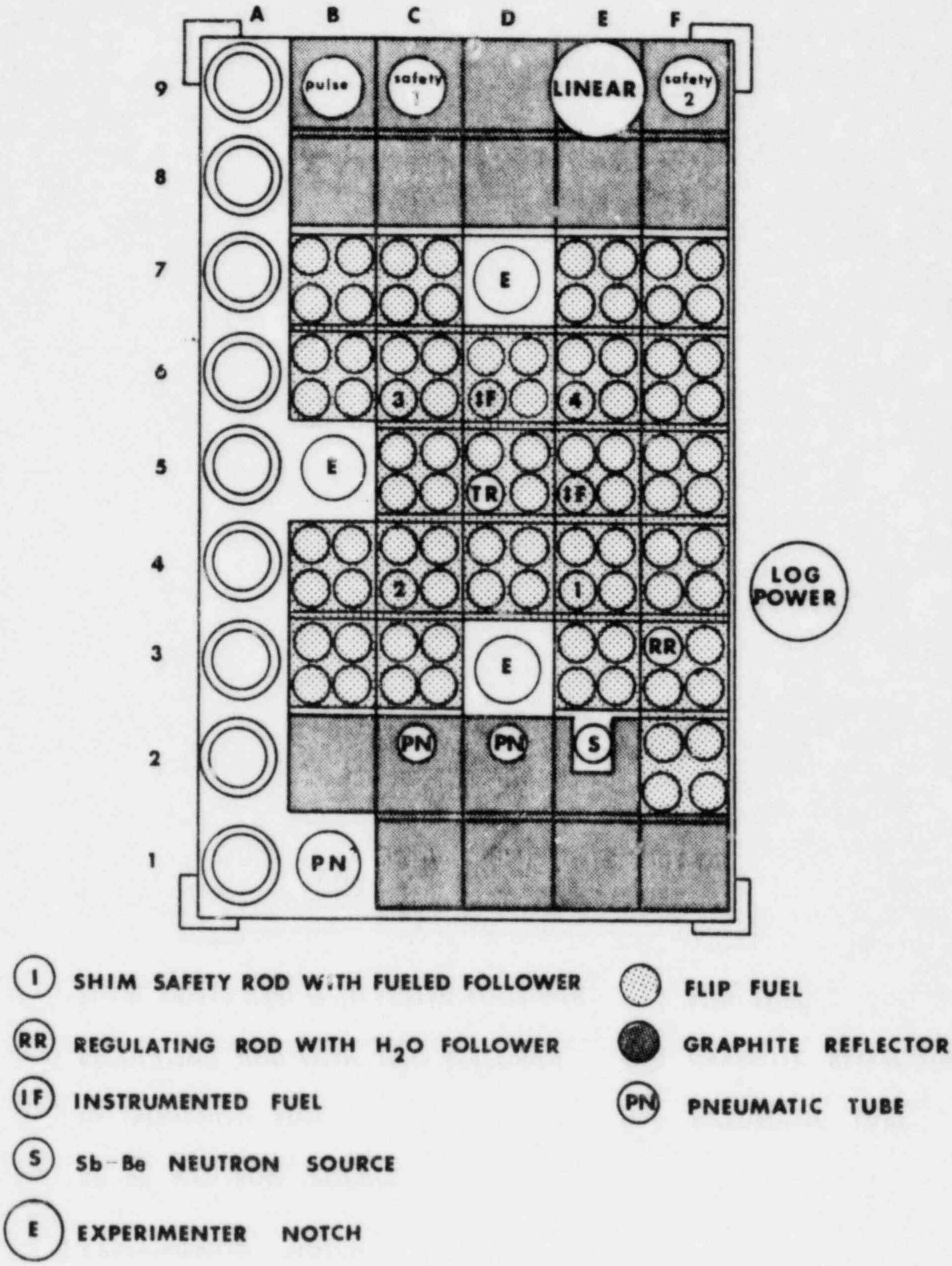
[1]"Interpretation of Damage to the FLIP Fuel During Operation of the Nuclear Science Center Reactor at Texas A&M University", M. T. Simnad, G. B. West, J. D. Randall, W. T. Richards and D. Stahl, General Atomic Company, GA-A16613, December 1981.



CORE VIII 90 FLIP ELEMENTS

Figure 1

(2) Establish limiting pulsing parameters for a given core.

(3) Obtain calibrations so that the peak core temperature and core pulse energy are known for a given reactivity insertion.

(4) Provide surveillance to detect fuel damage resulting from pulsing should damage occur.

III. Initial Conditions

Core VIII was established in December 1982 at which time the transient rod was installed and verified operational for steady state. In addition, the associated electronics have been successfully checked in the steady state mode of operation. For operation in the pulse mode all electronics and maintenance checks associated with the pulse measuring channel instrumentation and transient rod system will be completed and documented prior to entering the pulse test program. As a prelude to entering the test program certain high temperature elements designated to be monitored during the pulse program were removed from the core in January 1983 for visual inspection and measurement. It was at this time that a damaged element from past pulsing operations was discovered; therefore, the entire core was unloaded and inspected. A second damaged element was found, and both have been removed from the present Core VIII configuration.

IV. Code Calculations

The Exterminator-2 reactor code is used to determine the location of maximum pulse temperature fuel elements. Calculations have been completed for Core VIII, and based on this information the location of the peak core temperature has been determined, and the peaking factors between the IF thermocouple location and the peak core temperature location are known. This aids in establishing the IF temperature corresponding to core T_{max} = 830^{o}C (1526^{o}F) as the operational pulsing limit. Any future core loading will require calculation of maximum temperature locations and peaking factors to be followed by a pulse program of stepwise pulse reactivity insertion to establish pulsing parameters and limitations.

V. Fuel Element Inspection

In this program two methods of fuel inspection will be used independently or jointly as needed. One method of inspection is to visually observe the condition of fuel elements in a bundle assembly without breaking down the bundle. The second inspection method requires the measurement of elongation and bowing of individual elements.

Fuel bundles in grid positions E-5, D-4, and C-5 and their associated fuel elements have been selected for inspection at various stages of the pulse test program (see Core VIII, Figure 1). These bundle positions are east, south, and west of the transient rod bundle. These three grid position bundles selected for inspection contain six high temperature elements. Two are adjacent to the transient rod and four are adjacent to water filled flux traps. These grid locations also contain three of the five element positions where damaged fuel was discovered. These positions are C-5(SE), D-4(NW), and E-5(NW). Positions where the two other damaged elements were located, D-5(SE) and D-6(SE), will experience flux and temperature conditions almost identical to positions C-5(SE) and E-5(NW), respectively. Therefore, it is not essential to inspect the latter two positions at each inspection. However, they will be inspected at selected points in the program.

The instrumented elements in D-6(SW) and E-5(SW) will not be inspected due to potential loss of thermocouples during handling. The handling of elements in the transient rod bundle D-5 and the instrumented element bundle D-6 will be minimized as the handling of these bundles could result in damage to the transient rod and potential failure of the thermocouples in the instrumented element. It is essential to reactor operations that the IF in D-6(SW) is protected against damage due to handling.

The frequency selected for fuel inspections in the program is based primarily on the history of pulse operations of Core III-A prior to discovery of damaged fuel. During that period there were 455 pulses of $2.00 value, 54 pulses of $2.70 value, and 30 pulses between $2.00 and $2.70. Due to the absence of fuel inspections during operation of Core III-A there is insufficient data to establish the onset of fuel damage due to high temperature pulsing. However, it is reasonable to assume that the core was safely operated with damaged fuel for a long period and clearly without fuel element clad failure. (No fission products were released from any of the damaged elements.) It is also known that the two damaged elements discovered in January 1983 were in the core and operating at high power since termination of pulsing in September 1976. This has been a significant demonstration of fuel integrity considering that the NSCR operates approximately 100 megawatt days per year.

Based on the above discussion it is clear that reactor safety would not be compromised even with an inspection program that allowed large numbers of energetic (> \$2.00) pulses between inspections. However, in the first two phases of the test program the inspection intervals (see Sections VI and VII) involve numbers of pulses more than an order of magnitude less than the number of \$2.00 and \$2.70 pulses experienced by Core III-A. The goal is to perform frequent, selected inspections of the fuel to establish the onset of pulse damage should it occur. The inspection of fuel following the establishment of \$2.00 pulsing will provide base data for future inspections. The increased frequency of inspections at the higher pulse temperatures are required as these are the pulses that would most likely damage the fuel. The inspection of fuel after maximum pulse insertion has been estbalished will provide monitoring of the long term effect of pulsing in conjunction with normal steady state operation.

VI. Phase I of Full FLIP Pulse Test Program

In this initial pulse test program phase the reactor will be pulsed in stepwise increased pulse reactivity insertions of \$0.25 increments from \$1.00 up to and including \$2.00. Fuel element inspections are included in this phase. When \$2.00 is reached the following will be performed:

1. Determine by extrapolation the reactivity insertion value to produce a peak core temperature of $830^{o}C$ ($T_{max} = 1526^{o}F$).
2. Determine by extrapolation the pulse energy in MW-sec for the maximum pulse reactivity insertion required to produce a peak core temperature of $830^{o}C$ ($T_{max} = 1526^{o}F$).
3. Execute ten (10) pulses of \$2.00 insertion and compare observed temperatures and energy for reproducibility.
4. Halt pulsing and inspect the fuel elements of interest by visual and measurement methods (see Section V).
5. Prepare a report of the \$2.00 pulsing results for presentation to the RSB for review and approval to proceed to Phase II of the pulse test program.

6. Provide a copy of the results of Phase I to the USNRC (Washington and Region IV) following review and approval by the RSB.

   Note: Following Phase I fuel inspection and during the review and approval process period, the core may be pulsed at \$2.00 maximum reactivity insertion (assuming no damage was detected) for purposes of measurement of pulse nv and nvt and neutron flux mapping of experimental facilities.

VII. <u>Phase II of the Full FLIP Pulse Test Program</u>

In this phase the pulse reactivity insertion to produce a near maximum allowable core temperature ($1326^0F < \hat{T}$ core $< 1526^0F$) will be determined. Fuel element inspections are included in this phase of the pulse program.

1. From the extrapolated results of Phase I select the extrapolated value of the pulse reactivity insertion predicted to lie half-way between \$2.00 and the maximum allowable pulse insertion. (i.e., the pulse required to reach Tech Spec limits).
2. Pulse the reactor at the value obtained above and immediately inspect visually the fuel elements of interest (see Section V).
3. After reassembly of the core select a pulse reactivity insertion of near maximum allowable value. The selection should result in a maximum pulse core temperature between the limits of 1326^0F and 1526^0F.
4. Pulse the reactor at the near maximum allowable pulse insertion and immediately inspect visually the fuel elements of interest (see Section V).
5. Execute five (5) near maximum pulses and compare observed temperature and energy for reproducibility.
6. Halt pulsing and immediately inspect fuel by visual means and direct measurement of elongation and bowing. In addition to the fuel elements previously inspected during the pulse test program, the elements in the instrumented and transient rod bundles will be inspected.
7. Prepare a report of the near maximum pulsing results for presentation to the RSB for review and approval to proceed to Phase III of the pulse test program.
8. Provide a copy of the results of Phase II to the USNRC (Washington and Region IV) following review and approval by the RSB.

Note: The reactor may be pulsed during the review and approval period of Phase II assuming no damage was detected. Pulse insertion values will be limited to one-half the value between $2.00 and maximum allowable insertion.

VIII. Phase III of the Full FLIP Pulse Test Program

This phase of the program represents continued surveillance of fuel for pulse damage should it occur. This phase is designed to complement the proposed fuel surveillance requirements of the Technical Specifications for renewal of License R-83. The new Technical Specifications will require an annual fuel inspection program. This phase will require the following fuel inspections:

1. The elements of interest as described in Section V will be inspected as follows:
   (a) Visual inspection following each 25 pulses of reactivity insertion value equal to or less than the value lying half-way between $2.00 and the maximum allowable reactivity insertion, and
   (b) Visual and measured inspection following each 15 pulses of reactivity greater than the largest value described in (a) above.
   (c) Inspection annually of fuel in accordance with Technical Specification requirements.
2. This inspection program will continue as follows:
   (a) Until the total number of pulses of 1(a) has reached 75, or
   (b) Until the total number of pulses of 1(b) has reached 45, whichever comes first.
   (Note that this will extend beyond the total equivalent pulsing of Core III-A).
   (c) Following completion of the requirements of 2(a,b) the elements in the instrumented and transient rod bundles will be inspected by visual and measurement methods.
   (d) Annual inspection of fuel will be performed in accordance with Technical Specification requirements.

APPENDIX A

OPERATING HISTORY AND CORE CONFIGURATIONS FOR THE NSCR FROM SEPTEMBER 1976 TO PRESENT

Following the initial discovery of fuel element damage in September, 1976 the NSCR continued to operate in the steady state mode using the Core III-A configuration for approximately three months. Figures showing Core III-A and all core loadings used since that time are attached in this appendix.

Reactor core loading IV-A of 59 FLIP TRIGA elements and 39 standard TRIGA elements became operational on 10 January 1977. The new core loading was placed into service as part of the continuing upgrade program toward a full FLIP core loading. Core loading IV-B which became operational on 13 June 1977 differs from IV-A only by removal of the transient control rod from the core.

The NSCR continued to operate in the steady state mode using a mixed core configuration until November 1979. At that time Core V was established and contained 83 FLIP elements with a total excess reactivity of $2.90. Since this was not sufficient excess reactivity to maintain an operational core and meet utilization requirements, the loading was modified by the addition of 4 FLIP elements. This loading was designated Core VI and was established in November 1979. It contained 87 FLIP elements with a total excess reactivity of $5.73. Increased utilization was achieved by providing irradiation positions (flux traps) on the periphery of the core. These positions are vacant fuel bundle locations approximately 3" x 3" in cross sectional area.

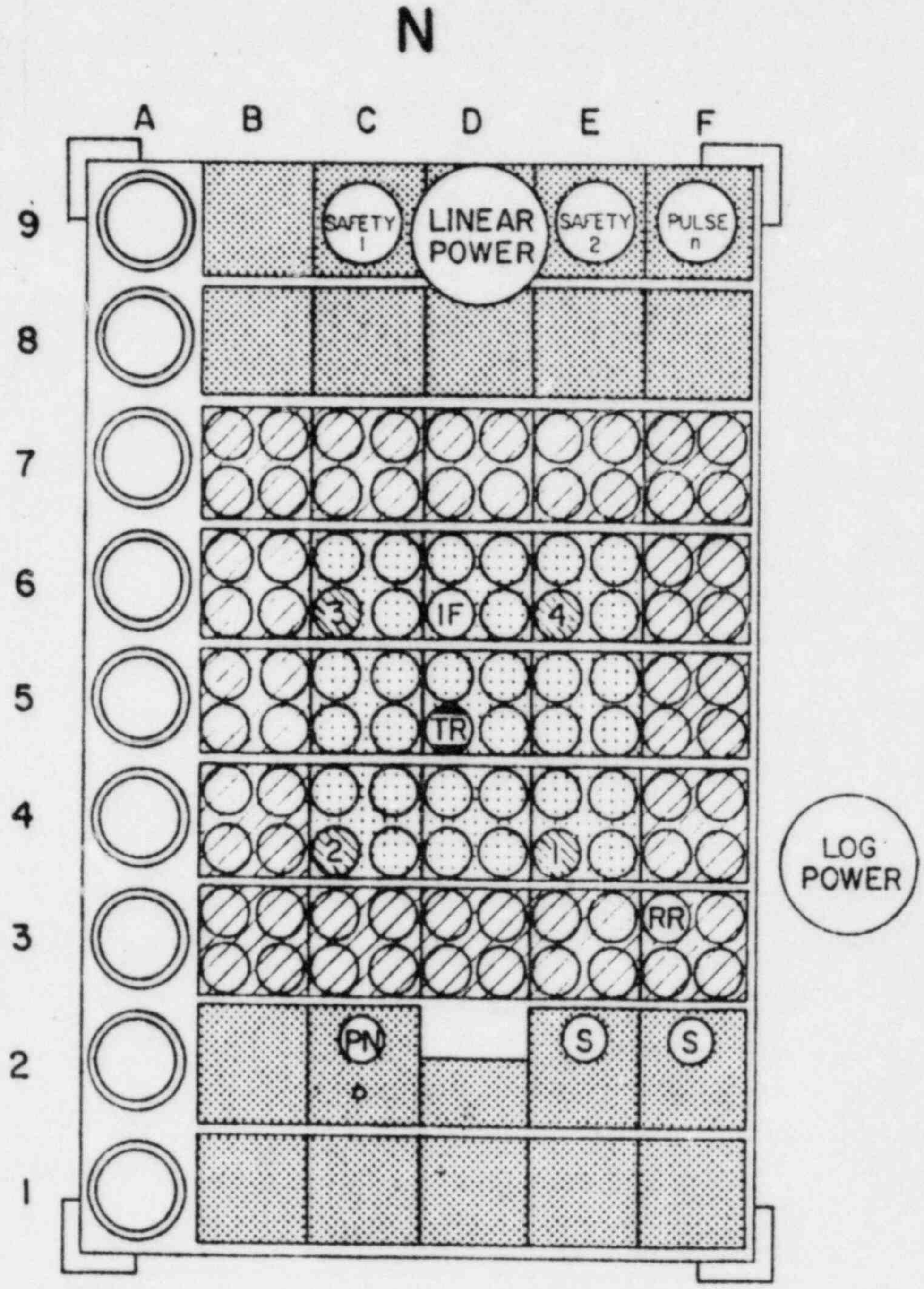
In an effort to increase the availability of neutrons on the east face of the reactor Core VI was modified to Core VI-A in December 1980 by moving the fuel bundle from D-7 to F-5. Tests confirmed not only an increase in the east face neutron flux but a flattened flux shape as well. This core was only operated as needed for neutron radiography, and through April, 1981 Core VI continued to be the primary core loading. At that time Core VII was established by adding an additional fuel bundle in F-2 to the Core VI-A design. In addition the neutron source was repositioned to the D-2/E-2 grid locations. Core VII was established to flatten the east face flux available to the multiple rotisserie irradiation device (MRID) and operated until January 1982 at which time Core VII-A was established. As seen in the attached figures this minor change to Core VII included the installation of an additional pneumatic receiver in D-2 and the consolidation of the neutron source into one tube in E-2.

Core VII-A continued to operate through December, 1982 at which time the transient rod was installed in D-5 and Core VIII was established. This core was loaded in preparation for reentering the pulse mode of operation and has operated satisfactorily in the steady state mode since being loaded. Up to the present time there has been approximately 650 megawatt days of steady state operation since the discovery of fuel element damage in September, 1976.

Table I has been provided to summarize the operating history of various configurations used since September, 1976.

TABLE I

Core	Date	Approximate MW-Days
III-A	September '76 - January '77	32
IV-A, IV-B	January '77 - November '79	265
IV	November '79	2
VI, VI-A	November '79 - April '81	125
VII, VII-A	April '81 - December '82	220
VIII	December '82 - Present	10



TR Transient Rod With Air Follower

1 Shim Safety Rod With Fueled Follower

RR Regulating Rod With H_2O Follower

IF Instrumented Fuel

S Sb-Be Neutron Source

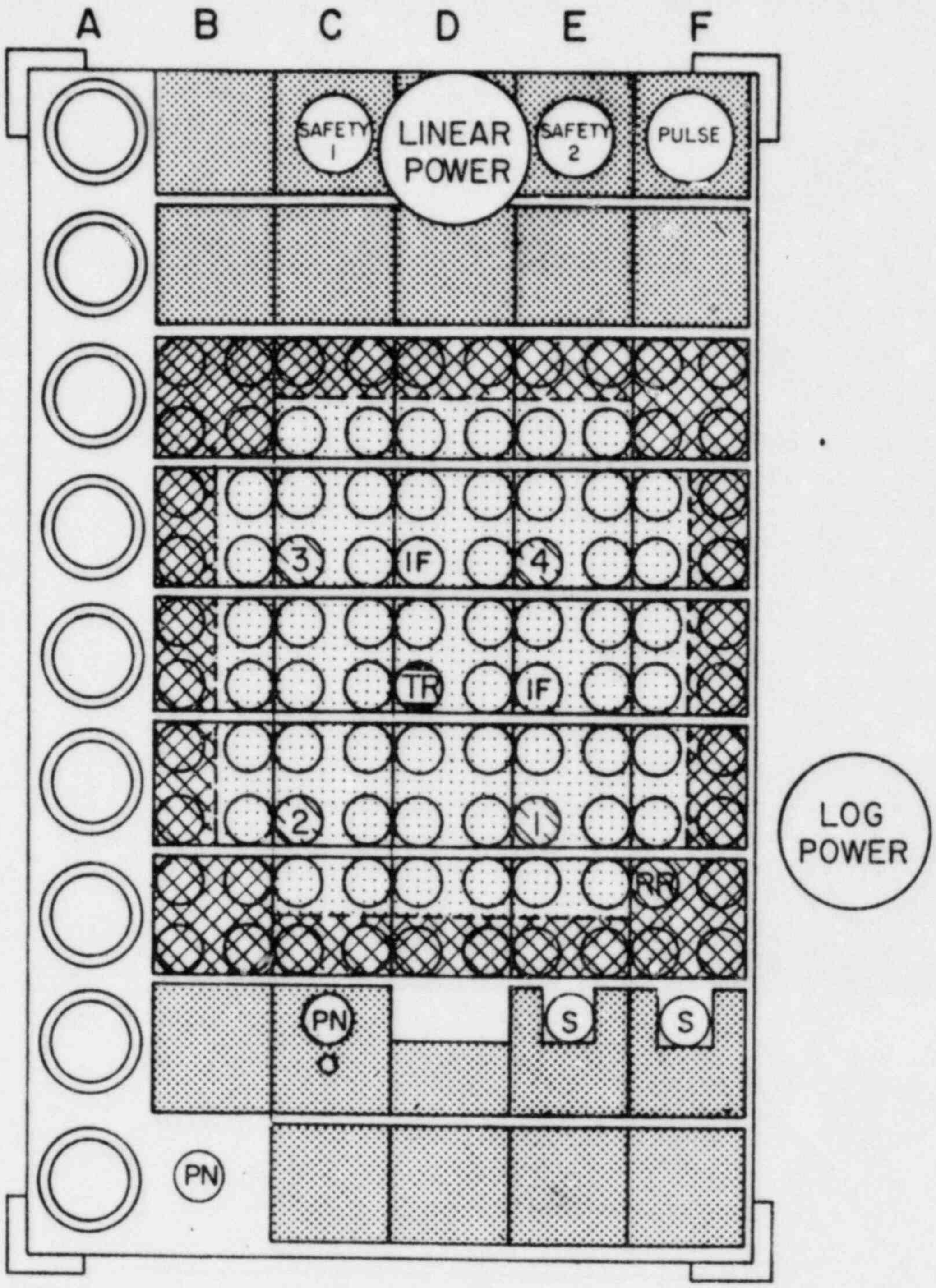
Standard Fuel

Flip Fuel

Graphite Reflector

PN Pneumatic Tube

CORE III - A



TR Transient Rod With Air Follower

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Standard Fuel

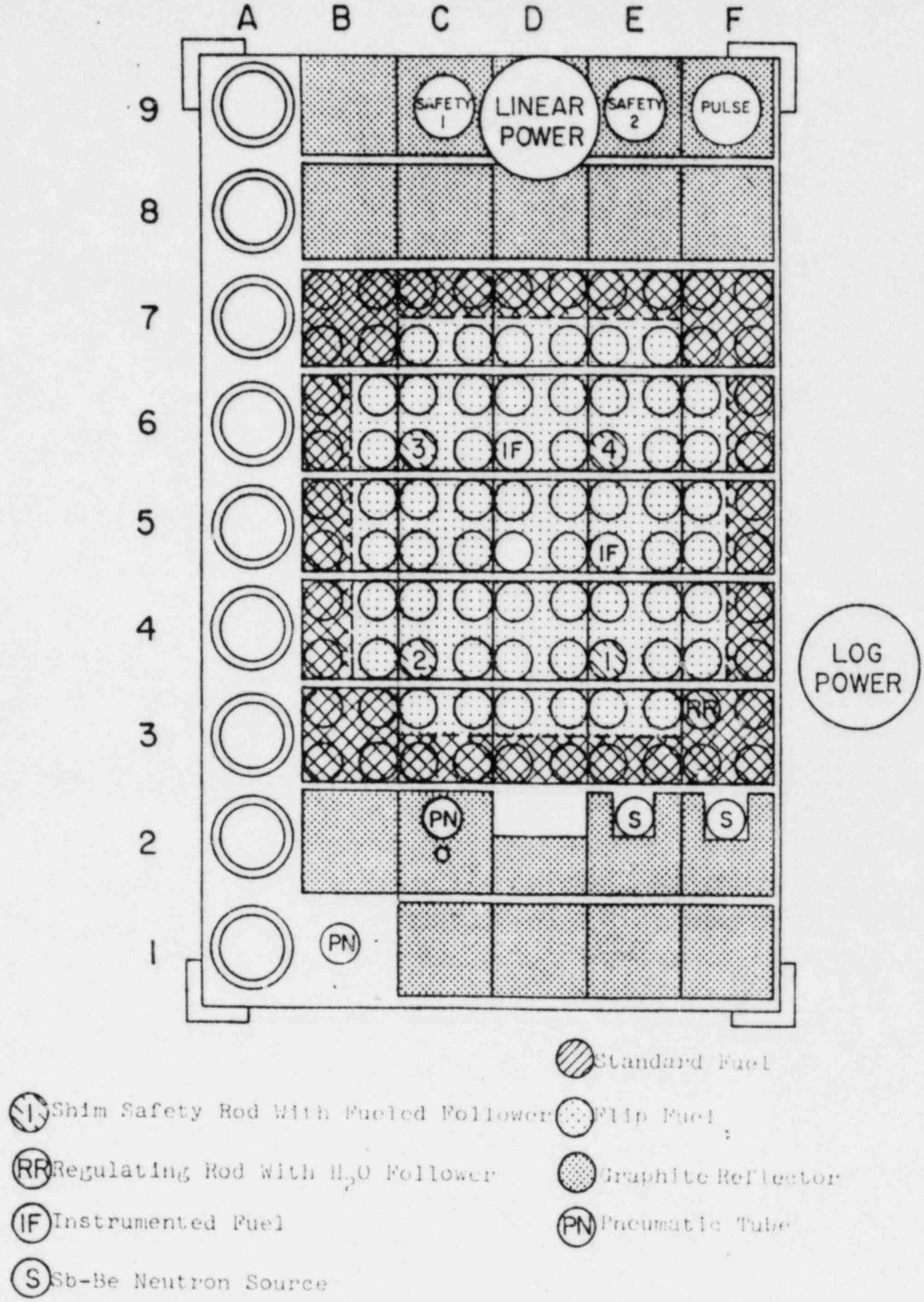
Flip Fuel

Graphite Reflector

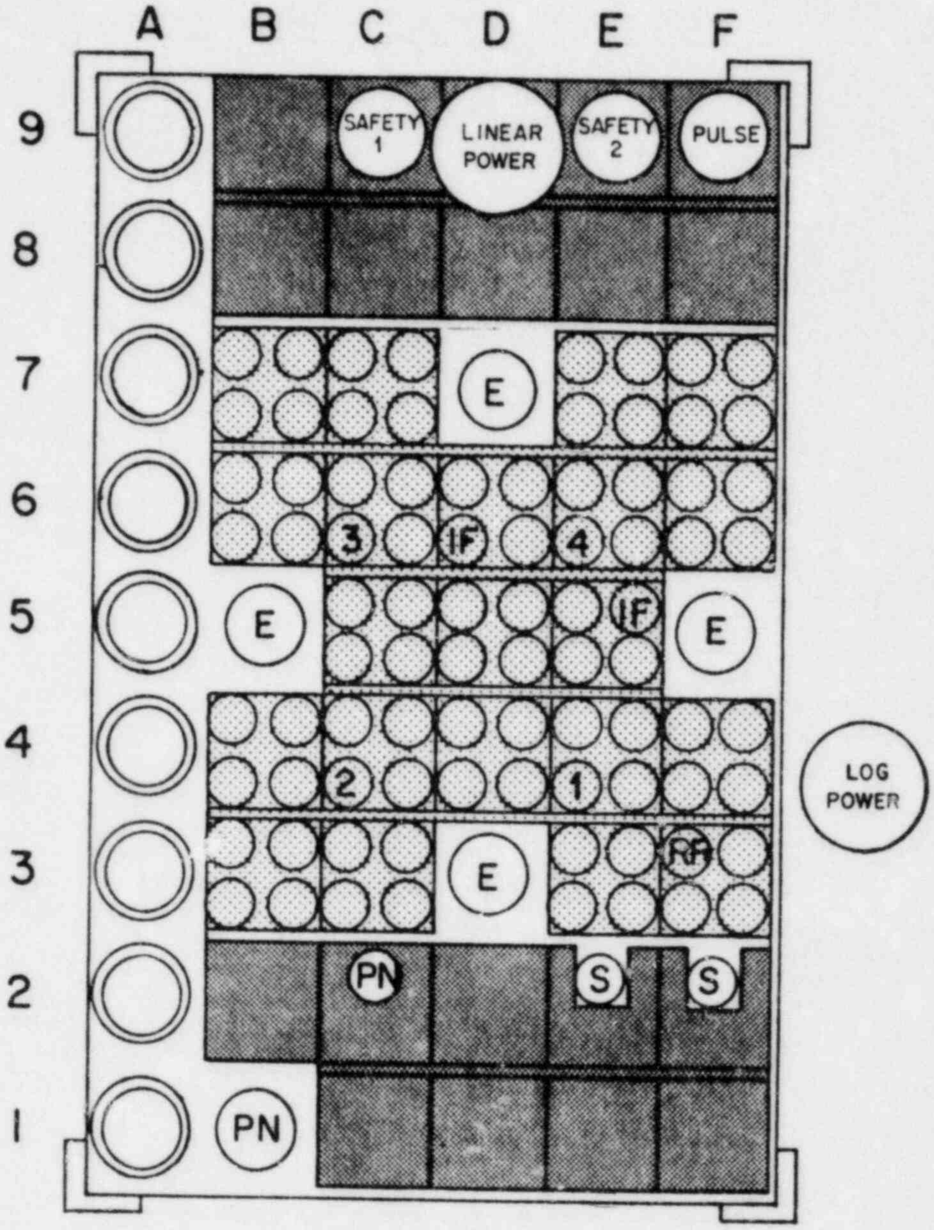
PN Pneumatic Tube

k_{ex} = \$7.34

NSCR CORE IV-A



NSCR CORE IV-B



1 SHIM SAFETY ROD WITH FUELED FOLLOWER

RR REGULATING ROD WITH H_2O FOLLOWER

IF INSTRUMENTED FUEL

S Sb-Be NEUTRON SOURCE

E EXPERIMENTER NOTCH

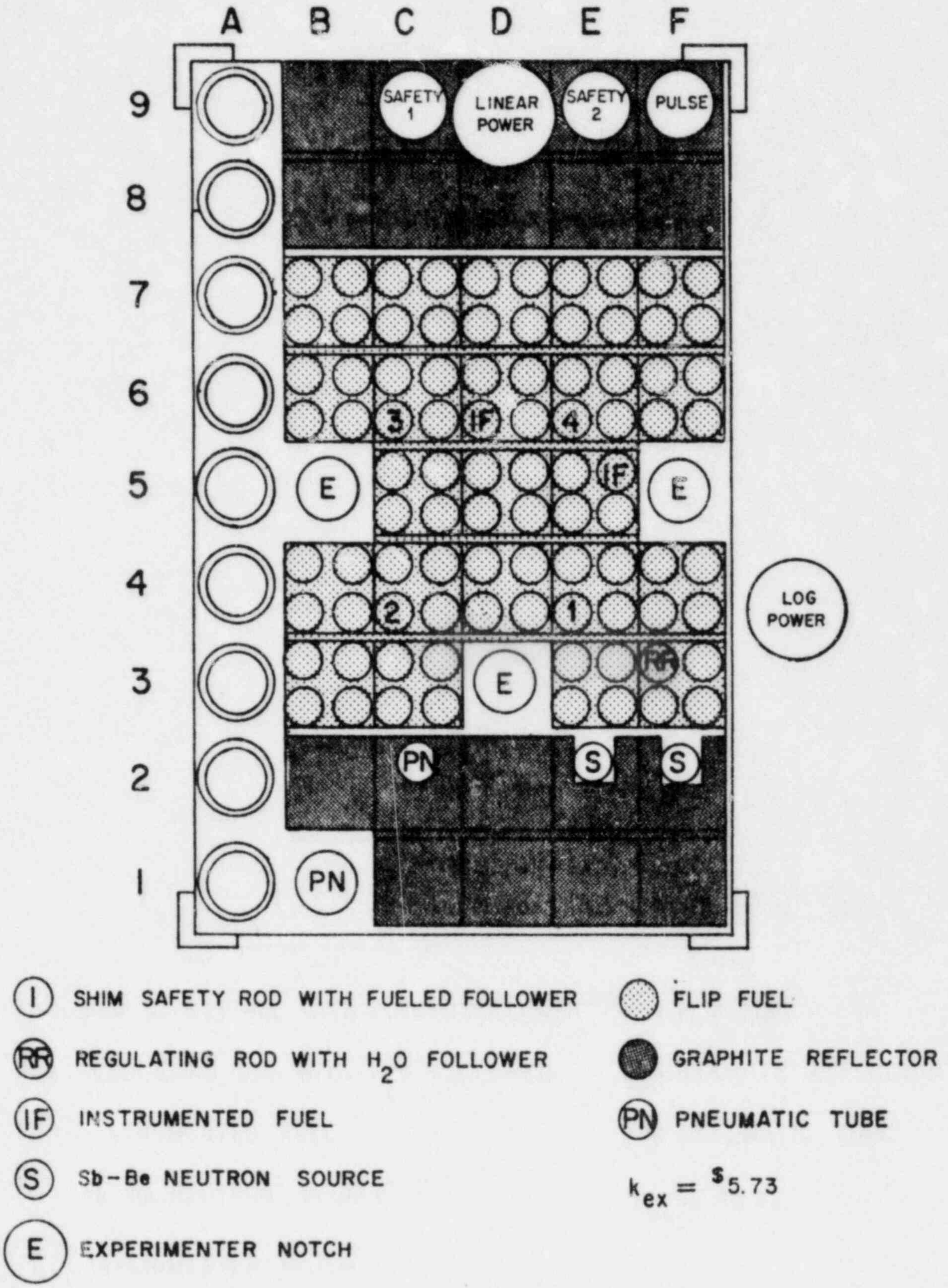
FLIP FUEL

GRAPHITE REFLECTOR

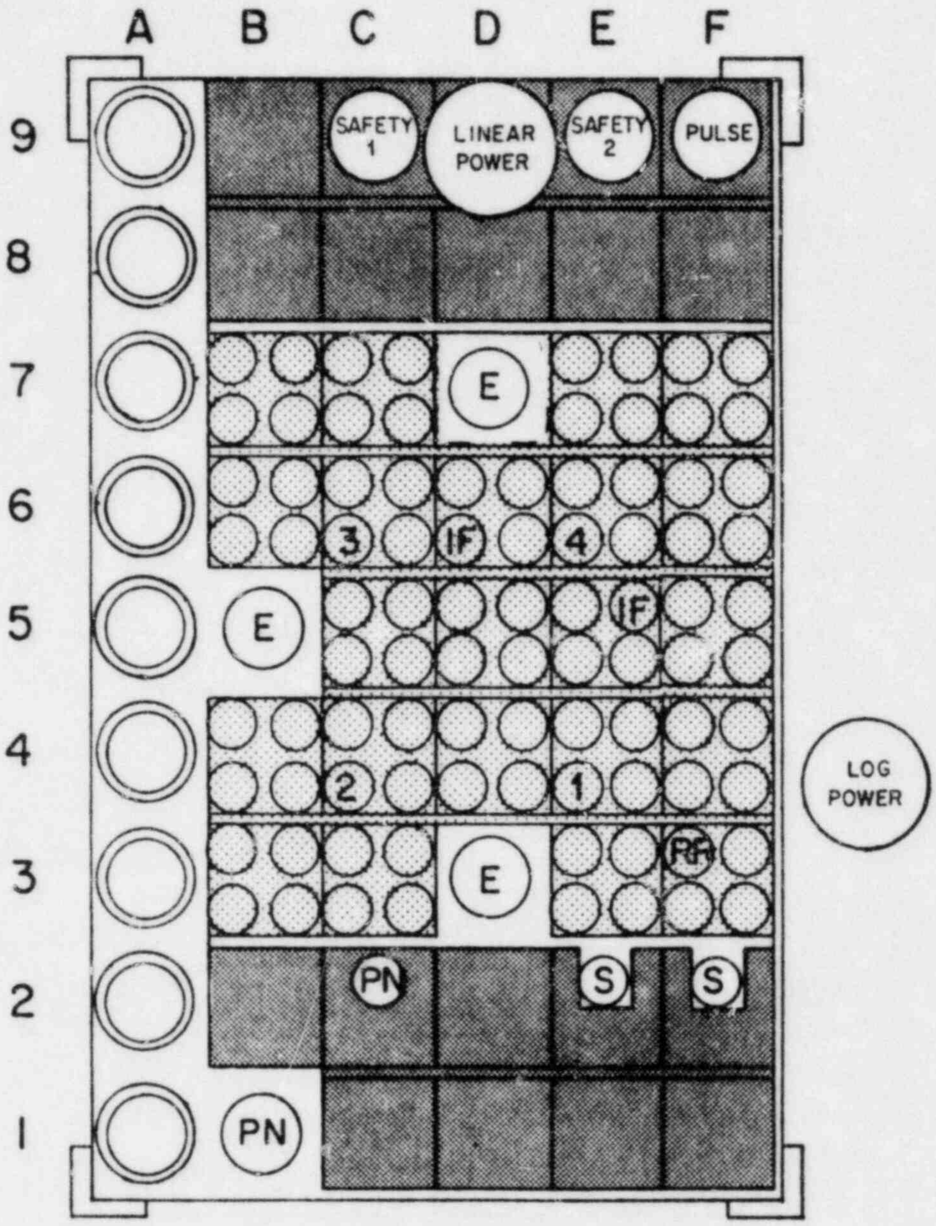
PN PNEUMATIC TUBE

NSCR CORE V

83 FLIP ELEMENTS



CORE VI, 87 FLIP ELEMENTS



(I) SHIM SAFETY ROD WITH FUELED FOLLOWER

(RR) REGULATING ROD WITH H_2O FOLLOWER

(IF) INSTRUMENTED FUEL

(S) Sb-Be NEUTRON SOURCE

(E) EXPERIMENTER NOTCH

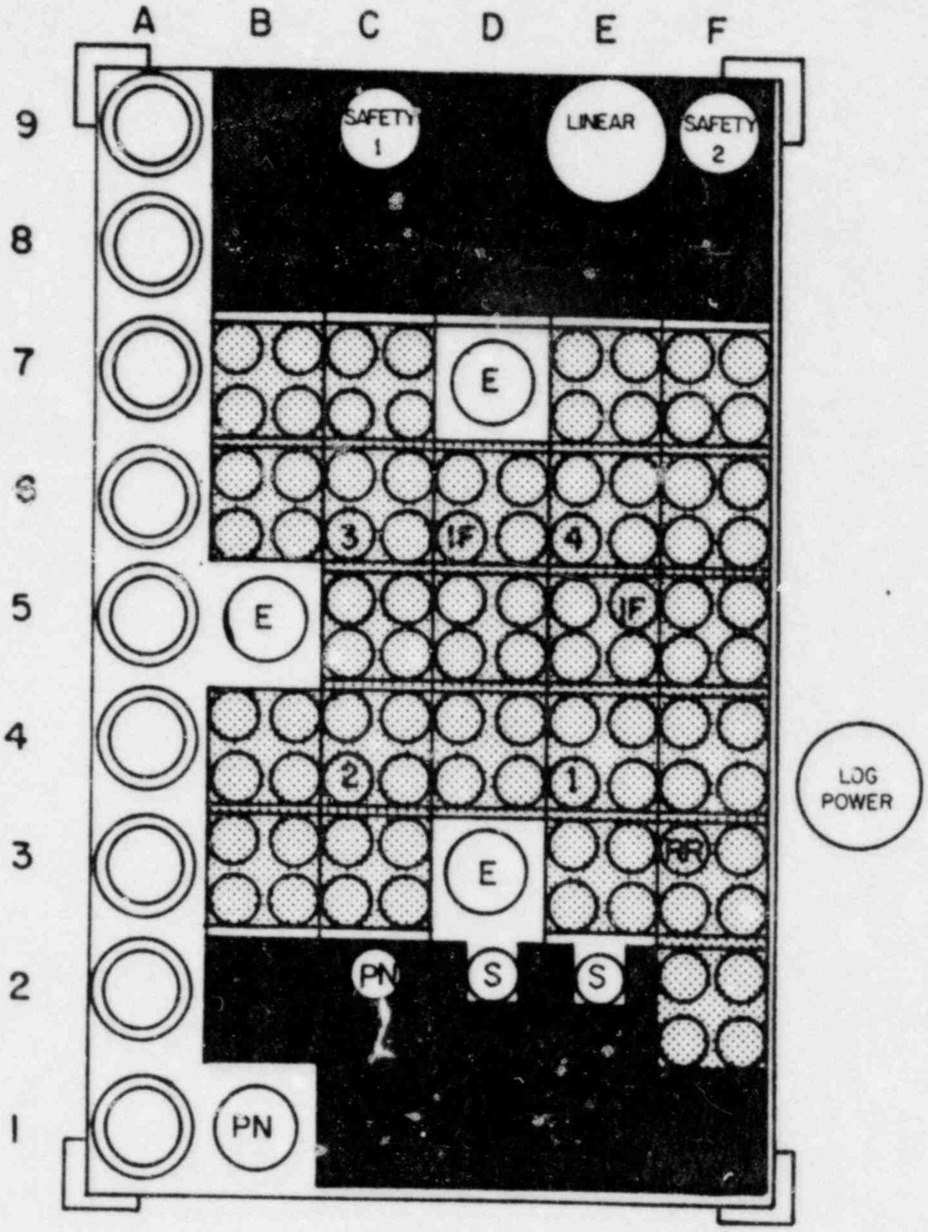
FLIP FUEL

GRAPHITE REFLECTOR

(PN) PNEUMATIC TUBE

$k_{ex} = \$5.84$

CORE VI-A, 87 FLIP ELEMENTS



(1) SHIM SAFETY ROD WITH FUELED FOLLOWER

(RR) REGULATING ROD WITH H_2O FOLLOWER

(IF) INSTRUMENTED FUEL

(S) Sb-Be NEUTRON SOURCE

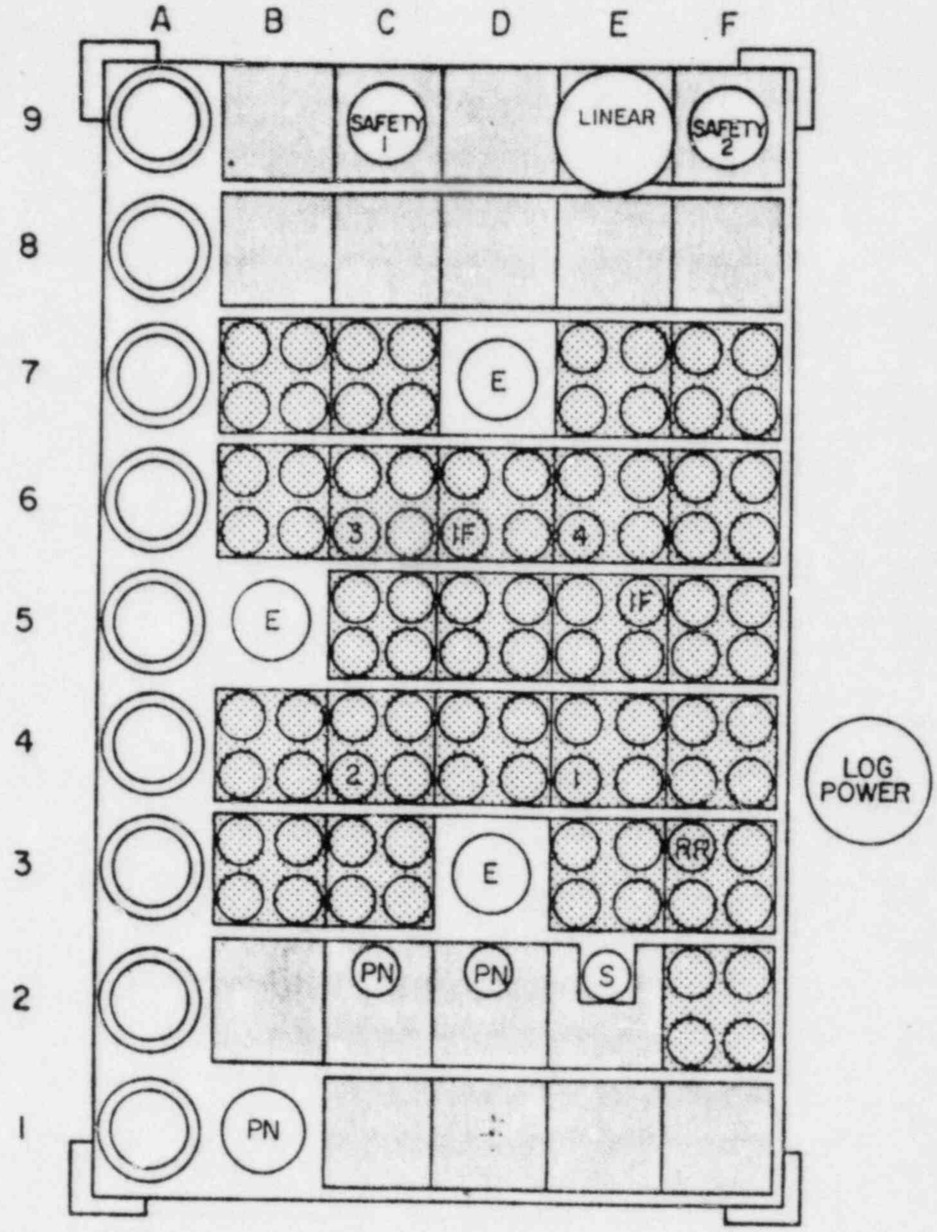
(E) EXPERIMENTER NOTCH

FLIP FUEL

GRAPHITE REFLECTOR

(PN) PNEUMATIC TUBE

CORE VII, 91 FLIP ELEMENTS



(I) SHIM SAFETY ROD WITH FUELED FOLLOWER

(RR) REGULATING ROD WITH H_2O FOLLOWER

(IF) INSTRUMENTED FUEL

(S) Sb-Be NEUTRON SOURCE

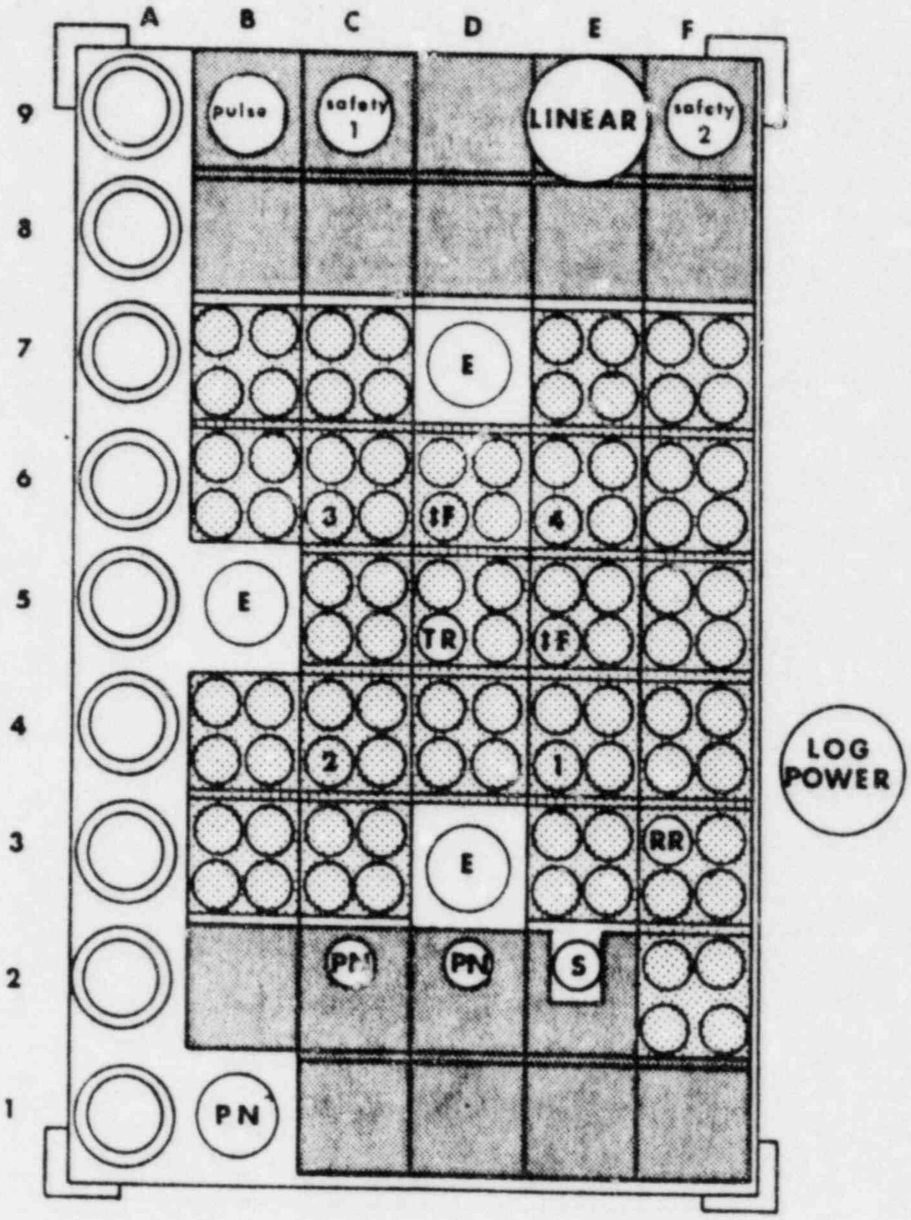
(E) EXPERIMENTER NOTCH

FLIP FUEL

GRAPHITE REFLECTOR

(PN) PNEUMATIC TUBE

CORE VII-A 91 FLIP ELEMENTS



(1) SHIM SAFETY ROD WITH FUELED FOLLOWER

(RR) REGULATING ROD WITH H_2O FOLLOWER

(IF) INSTRUMENTED FUEL

(S) Sb-Be NEUTRON SOURCE

(E) EXPERIMENTER NOTCH

FLIP FUEL

GRAPHITE REFLECTOR

(PN) PNEUMATIC TUBE

CORE VIII 90 FLIP ELEMENTS