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SM-1
RESEARCH AND DEVELOPMENT
TASK XV
ZERO POWER EXPERIMENTS FOR SM-1 CORE II AND SM-1A CORE I

ALCO

ALCO PRODUCTS, INC.
NUCLEAR POWER ENGINEERING DEPARTMENT
P. O. BOX 414, SCHENECTADY 1, N. Y.

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SM-1 RESEARCH AND DEVELOPMENT

TASK XV
ZERO POWER EXPERIMENTS FOR SM-1 CORE II AND SM-1A CORE I

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ABSTRACT

A zero power experiment on the SM-1 Core II included an element by element reactivity check of fuel elements and control rod absorber sections, and an estimate of burnable nuclear poison loading in stationary fuel elements. An approach to criticality was made by the inverse multiplication method, and critical rod bank position obtained as a function of fuel loading up to full core loading. Minimum and maximum core reactivity measurements were obtained by selective loading of stationary fuel elements, and total excess K of the core was established.

Power distribution measurements were taken in the regions of the core-reflector interface and the fuel-absorber interface in the control rod assemblies. The effectiveness of europium flux suppressors in the top of control rod fuel elements was determined, and power peaking was measured in stationary elements adjacent to control rod assembly water gaps.

Survey measurements established the worth of spiking clean, cold SM-1 cores with SM-2 elements and the worth of water holes in the SM-1 Core.

The reduced scope zero power experiment performed on SM-1A core I included an element by element uniformity check of stationary fuel elements, a core assembly test, comparison of Eu_2O_3 and B_4C absorber sections, and development of initial core loading procedures for the SM-1A plant.

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SUMMARY

The standard sample technique and experimentally determined B-10 worth were used to obtain an estimated B-10 loading of 13.96 gm in the stationary fuel elements of SM-1 Core II. A five rod bank critical position of 4.153 in. withdrawal was obtained with control rods A and B withdrawn to 21.763 in. and random distribution of stationary fuel elements in the reactor lattice. Selective distribution of stationary elements produced five rod critical bank positions of 3.923 and 4.333 in. for maximum and minimum reactive cores.

Excellent uniformity exists within the SM-1 Core II europium control rod absorber sections; however, the europium absorbers control approximately 16 cents less reactivity when fully inserted in the SM-1 core than the boron absorber they were compared against. Reactivity worth of a water hole in the SM-1 core ranged from 37.1 cents in position 21 to 157.3 cents in position 34, and the reactivity change resulting from the substitution of an SM-2 mock-up element into a cold, clean SM-1 core averaged about 5 cents.

Power mapping in the region of the fuel absorber interface of the control rod assemblies established the adequacy of integral europium flux suppressors at the top of control rod fuel elements. The water gap between control rod fuel and absorber sections introduces a local power spike on the outside fuel plate of adjacent stationary elements; however, this spike does not exceed the maximum power generated in the center plate.

For SM-1A Core I, a five rod bank critical position of 3.642 in. withdrawn was obtained using Eu_2O_3 absorber sections, with control rods A and B fully withdrawn. The same measurement with B_4C absorbers produced a five rod bank critical position of 4.092 in. withdrawn. A 13.34 gm B-10 loading in SM-1A Core I stationary fuel elements was estimated. Four stationary elements were rejected because of non-uniform B-10 or U-235 loading.

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INTRODUCTION

Burnable nuclear poisons are often utilized to minimize control requirements in reactor cores containing highly enriched fuel, as the SM-1. The most commonly used burnable poison, B-10 (as B_4C), is lost in varying degrees from the fuel matrix during the sintering, heating, and hot rolling processes, necessitating individual element and assembly tests on a new core to verify core safety. In addition, technological advances resulting from these tests often permit core modification, producing increased performance and reliability.

SM-1 Core II is the second operational core produced for the Army's Fort Belvoir plant. The second core includes internal flux suppressors at the top of the control rod fuel elements and europium-bearing absorber sections. These modifications dictated a zero power experiment to estimate boron loading, its uniformity of distribution, the effectiveness of integral flux suppressors in control rod elements, and the worth of europium absorbers. In addition, limited measurements of the power distribution were made at the core-reflector interface and around water gaps in control rod assemblies. Survey reactivity measurements were made in support of the decision to insert two SM-2 elements in the SM-1 core, and to determine the effect of water holes.

The zero power experiment was performed on SM-1A Core I, essentially a production core, to insure its uniformity and adequacy, and to establish initial core loading procedures.

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1.0 SYSTEM DESCRIPTION

1.1 INTRODUCTION

A detailed description of the experimental assembly and its relationships to this Facility [1] is presented in the Hazards Summary Report for the SM-2 Critical Experiments [2] and the Hazards Summary Report on the Zero Power Experiments for the Army Package Power Reactor.[3]

This chapter describes experimental techniques and core assembly, and defines system nomenclature for the reader's convenience.

1.2 EXPERIMENTAL ASSEMBLY

1.2.1 Core Support Assembly

The core support assembly, a three-tiered stainless steel table located over the center of the reactor tank floor at the Facility, has the potential of accommodating reactor cores with a total of 89 fuel elements and control rods, although a maximum of 38 fuel elements and 7 control rods were required for the 7 by 7 SM-1 array. Structural support, alignment, and position of the assembly are assured by tie rods and spacers as shown in Fig. 1.1.

1.2.2 Control Rod Assembly

Reactor control is maintained by the insertion or withdrawal of control rod assemblies, Fig. 1.2, containing both nuclear fuel and box-type boron or europium absorbers. The assemblies have overhead drives, Fig. 1.2, and drop by gravity on scram. Guide rods and dashpot plungers to act as guides and decelerative devices respectively are attached to the ends of the control rod baskets.

1.2.3 Fuel Element Assembly - SM-1, Core II

The stationary fuel elements contain 18 stainless steel - UO_2 matrix fuel plates, each loaded with 28.62 gm U-235. Control rod fuel elements have 16 similar fuel plates loaded with 26.07 gm U-235 and contain a europium neutron flux suppressor section at the top 7/8-in. of the matrix. The matrix is 0.020-in. thick and is clad with 0.005-in. stainless steel. Fuel plate dimensions are indicated on Fig. 3.3. Complete specifications for the stationary fuel element may be found in reference 10, while references 11 and 12 give control rod fuel element and absorber section specifications. Figures 1.4 and 1.5 depict an SM-1 Core II stationary fuel element and control rod fuel element.

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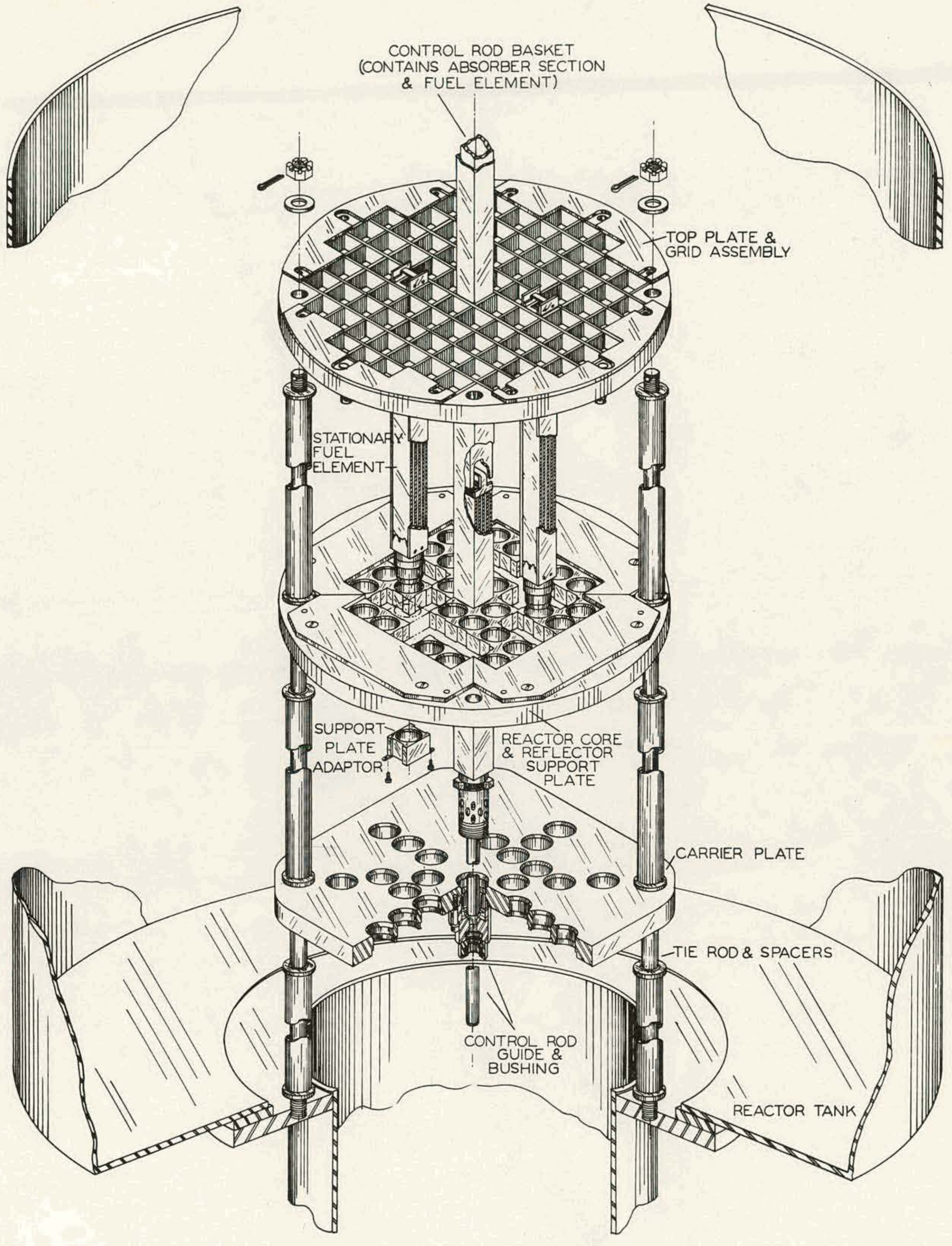

FIG. 1. 1 - Core Support Structure

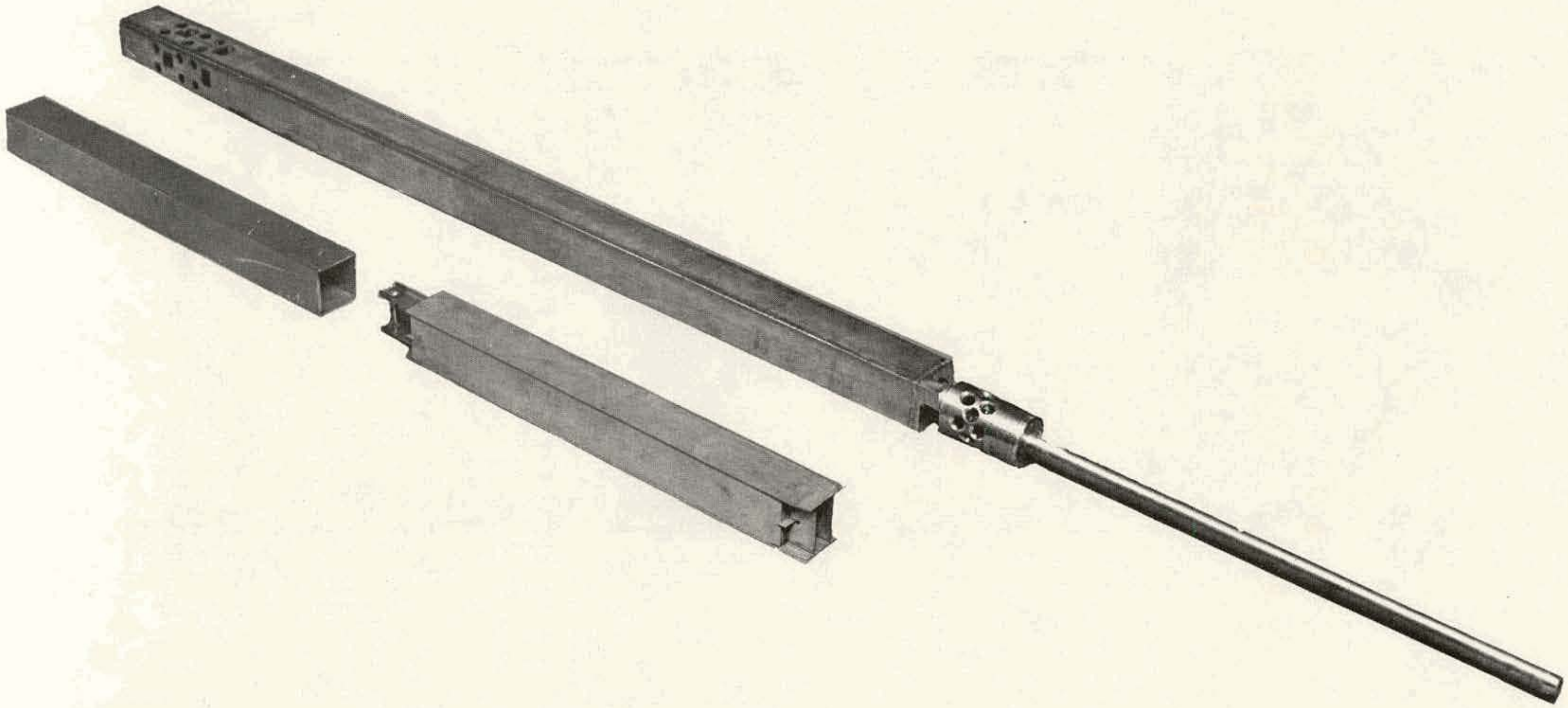

Fig. 1.3 Control Rod Assembly

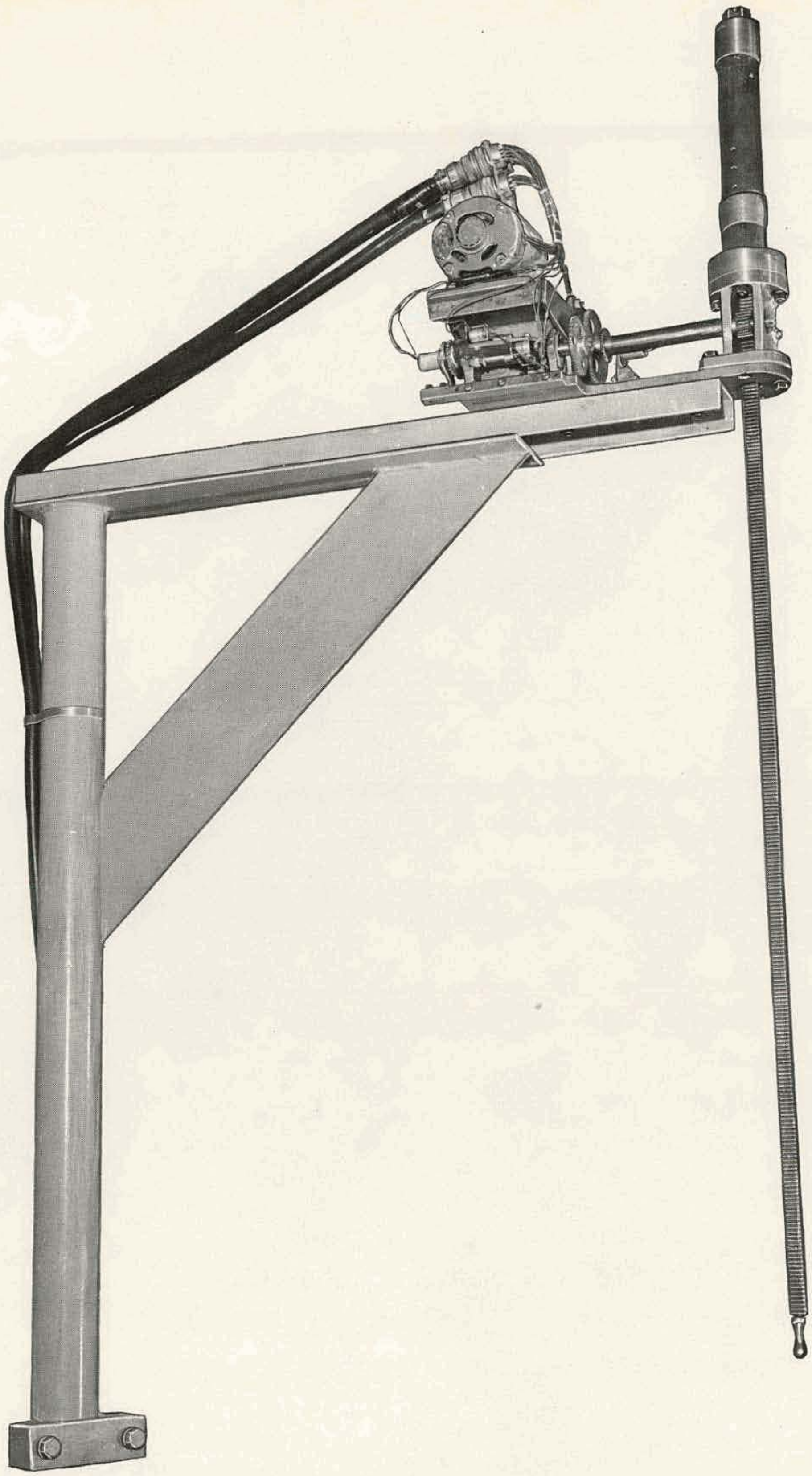

Fig. 1. 3 Control Rod Drive

Fig. 1.4 Stationary Fuel Element

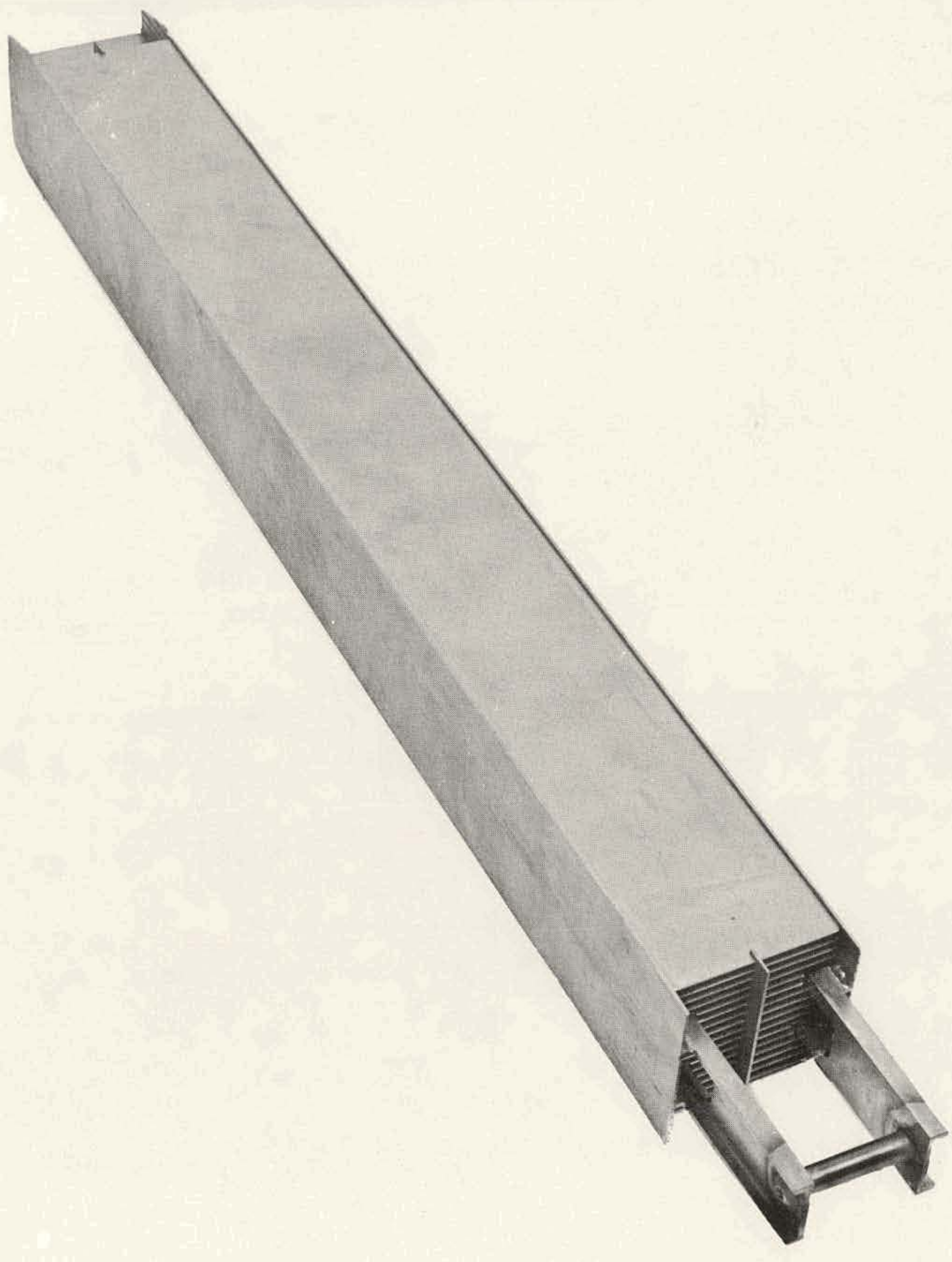

FIG. 1. 5 - SM-1 Core II Control Rod Fuel Element

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1.3 NOMENCLATURE AND EXPLANATIONS

1.3.1 Active core	that region defined by upper and lower average limits of U-235 distributions in stationary fuel elements and cell boundaries of the outer row of stationary elements.
1.3.2 Control rod withdrawal	withdrawal of the absorber section of the control rod from the active core and consequent simultaneous insertion of fuel.
1.3.3 Control rod position	distance withdrawn (in.) from position of deepest insertion, which is defined as the nominal alignment of the bottom of the active core with the top of the europium flux suppressor.
1.3.4 Bank position	average positions of individual rods comprising the bank
1.3.5 Data point, experimental	all experimental data points are plotted as a point (circles, squares, etc.). Points derived from experimental data by cross plot or integration are indicated by crosses.
1.3.6 Temperature	all measurements at 65°F unless otherwise noted

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2.0 SM-1 CORE II ZPE III REACTIVITY MEASUREMENTS

2.1 INTRODUCTION

Measurements performed during SM-1 Core II ZPE checked uniformity of Core II elements and reactivity of the core assembly. Survey reactivity measurements estimated effects of spiking the SM-1 Core II with SM-2 elements, and effects of a water hole caused by removal of a fuel element. Boron loading of each Core II element was calculated, using a measured boron reactivity coefficient and the SM-1 standard element boron loading determined during CE-1.[4] Excess K of the core was determined from measurements taken during core assembly tests.

2.2 SM-1 CORE II ELEMENT CHECK

2.2.1 Procedure

Each Core II stationary element was checked using the SM-2 mockup core.[4] The Core II elements were individually substituted into element position 22 of the SM-2 mockup and compared with a standard SM-1 element in this same position. Control rod F, adjacent to position 22, was fully withdrawn so that its absorber section would not affect measurements in this quadrant. Rods A, B, D, E, and G were kept at 5.900 in. and the reactivity differences between each Core II element and the standard were measured in cents on calibrated control rod C. Core II control elements were checked for uniformity by loading six of the seven control rods with SM-2 mockup control elements while the seventh rod was kept fully withdrawn and Core II control elements substituted into it. Reactivity differences of the control elements were measured on the calibrated bank, in cents.

2.2.2 SM-1 Core II Stationary Element Boron Loading

To determine the boron variation between Core II elements and the standard SM-1 element, a B-10 reactivity coefficient of 117 cents per gm was measured for an SM-1 element substituted into position 22 of the SM-2 core. This value is greater than that normally measured in the SM-2 core with all the rods positioned as a bank.

Table 2.1 lists reactivity difference in cents between Core II elements and the standard, difference in grams of B-10 between Core II elements and the standard, and total B-10 content per Core II element based on an estimated 0.363 gm B-10 in the standard element.

TABLE 2.1

SM-1 CORE II STATIONARY ELEMENT BORON LOADING

Element Number	ΔK_E (cents)	Difference in B-10 Loading from standard (gm)	Total B-10 Loading (gm)
33	-2.41	+0.021	0.384
34	-4.85	+0.041	0.404
6	-9.63	+0.082	0.445
12	-0.17	+0.001	0.364
35	-8.05	+0.069	0.432
36	-2.63	+0.023	0.386
43	-4.09	+0.035	0.398
14	-8.21	+0.070	0.433
5	-11.63	+0.100	0.463
39	-4.70	+0.040	0.403
38	-4.85	+0.041	0.404
41	-6.02	+0.052	0.415
37	-4.62	+0.040	0.403
40	-5.17	+0.044	0.407
7	-4.57	+0.039	0.402
2	-4.68	+0.040	0.403
4	-8.25	+0.071	0.434
18	-0.33	+0.003	0.366
19	-0.60	+0.005	0.368
23	0	0.000	0.363
27	+0.38	-0.003	0.360
11	+14.66	-0.125	0.238
29	+2.40	-0.021	0.342
15	+7.03	-0.060	0.303
16	+7.52	-0.064	0.299
22	+4.53	-0.039	0.324
28	+2.65	-0.023	0.340
21	+3.54	-0.030	0.333
30	+0.88	-0.008	0.355
20	+1.59	-0.014	0.349
9	+1.64	-0.014	0.349
24	+5.07	-0.043	0.320
13	+4.02	-0.034	0.329
32	+1.98	-0.017	0.346
31	+3.30	-0.028	0.335
17	+2.03	-0.017	0.346
25	+2.64	-0.023	0.340
10	+9.97	-0.085	0.278
TOTAL	-19.63	+0.165	13.963

2.2.3 SM-1 Core II Control Rod Fuel Elements

As no standard existed with which to compare the Core II control rod elements, a uniformity check of one element against another was performed. Table 2.2 gives the variation, in cents, of each control rod fuel element from average reactivity of all seven.

TABLE 2.2
SM-1 CORE II CONTROL ROD FUEL ELEMENT UNIFORMITY

Control Rod No.	Deviation from Average (cents)
2	-4.21
3	+2.83
4	-0.62
5	+2.24
6	+1.99
7	+1.65
8	-3.94

2.3 SM-1 CORE II ABSORBER SECTION CHECK

2.3.1 Procedure

Three Core II europium absorbers were available and checked against a boron absorber section fabricated to SM-1 Core I specifications by fully inserting Rod C and substituting absorber sections into it. Reactivity differences were measured on the calibrated bank.

2.3.2 SM-1 Core II Absorber Section Uniformity

Table 2.3 lists the Core II europium absorbers, and their worth in comparison with the boron absorber, and gives an indication of their uniformity.

TABLE 2.3
SM-1 CORE II ABSORBER SECTION UNIFORMITY

Absorber Identification	Worth (cents)
Eu SS7	+16.2
Eu SS2	+16.3
Eu SS3	+16.4

2.4 ASSEMBLED SM-1 CORE II

2.4.1 Random Loaded Core

Due to variation in boron loading of Core II elements, core reactivity may be varied by element grouping. Three assemblies were tested: random loading without regard to boron loading, minimum reactive loading, and maximum reactive loading.

At random loading, criticality was obtained with 19 elements arranged as in Fig. 2.1. Five rod bank positions were obtained for 28 and 37 element cores as well as the final 45 element assembly; arrangements are shown in Fig. 2.2, 2.3, and 2.4. Five rod bank positions vs. total number of in-core elements are tabulated in Table 2.4 and plotted in Fig. 2.5. During these measurements, rods A and B were fully withdrawn (21.763 in.). Figures 2.1, 2.2, 2.3, and 2.4 indicate which core II elements are in various core positions. The absorbers used were the SM-2 mockup absorbers made to SM-1 Core I specifications.

TABLE 2.4
FIVE ROD BANK POSITION VS. NUMBER OF ELEMENTS

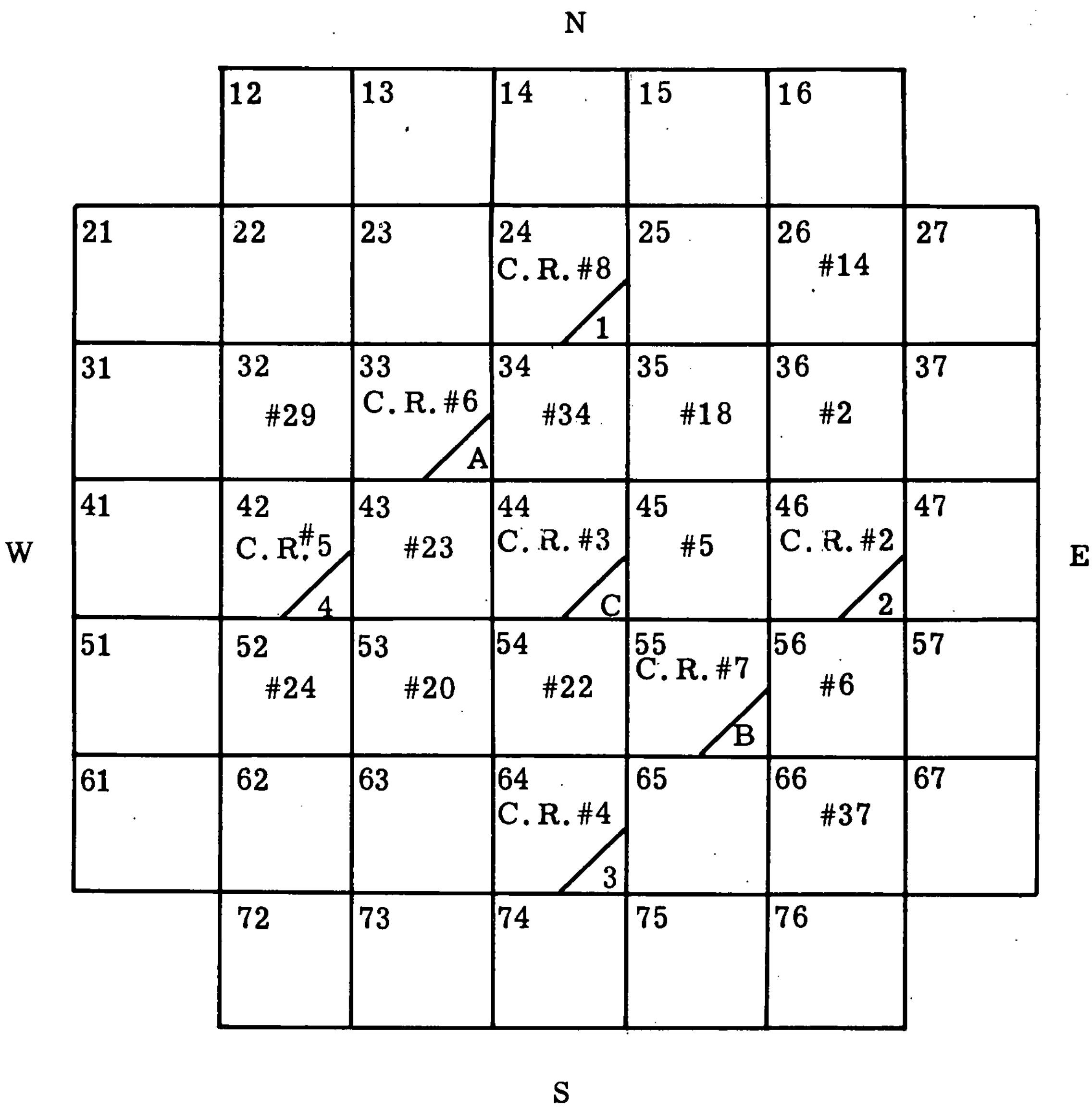
Number of Elements	Five Rod Bank Position
19	19.435 inches
28	9.902 inches
37	6.978 inches
45	4.153 inches

2.4.2 Minimum Reactive Core Loading

The minimum reactive core loading was assembled with the elements of highest boron loading in the center (Fig. 2.6). The five rod bank critical position and two calibration points were obtained with rods A and B fully withdrawn (21.763 in.).

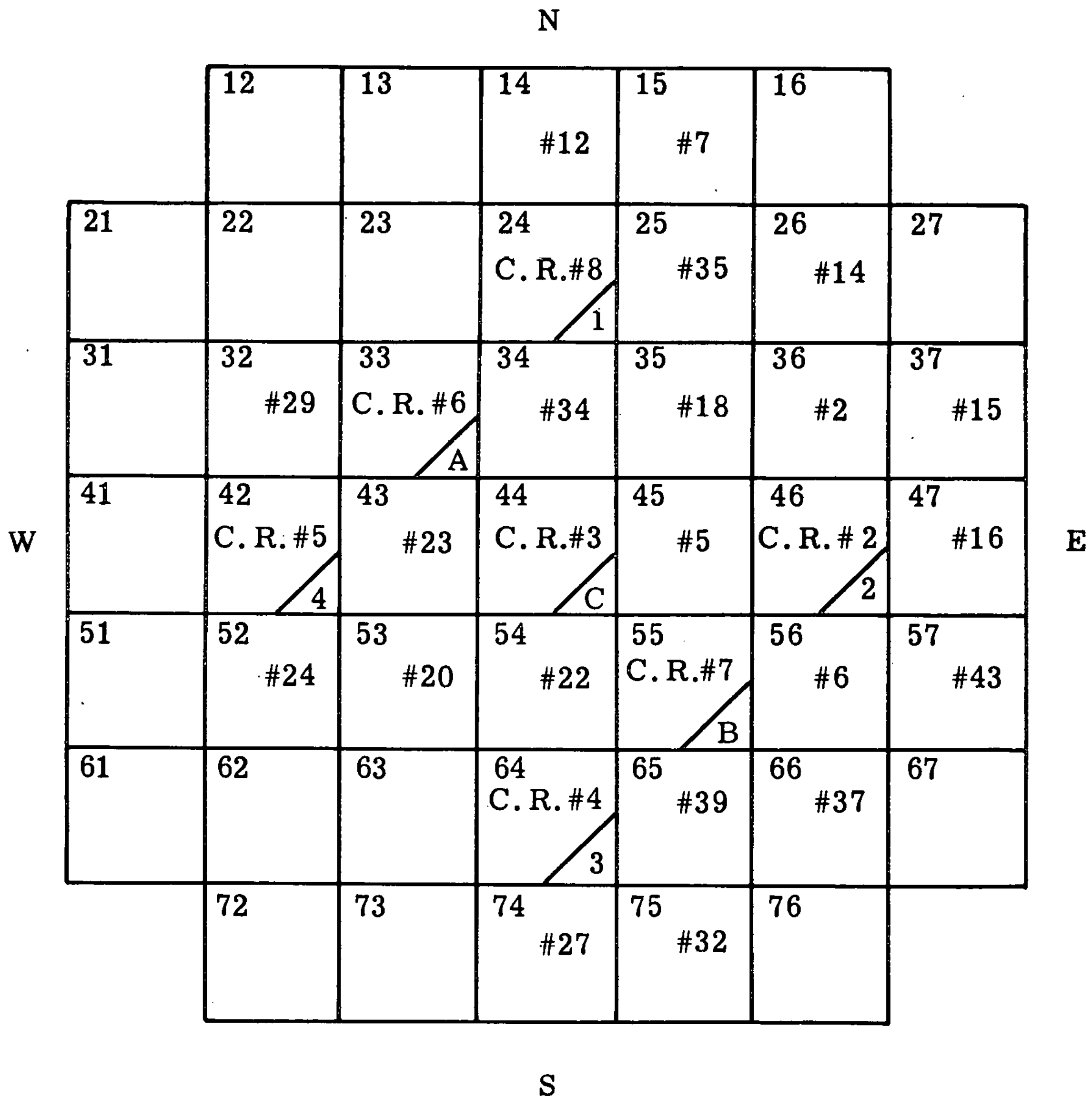
Five Rod Bank Critical Position - 4.333 in.

Five Rod Bank Worth - 162.0 cents per in. @ 4.370 in.
- 157.2 cents per in. @ 4.381 in.



8,989.76 gm. U^{235}

Fig. 2.1 SM-1 Core II - 19 Element Loading



13, 626. 20 gm. U^{235}

Fig. 2.2 SM-1 Core II - 28 Element Loading

N

		12	13 #13	14 #12	15 #7	16	
	21	22 #41	23 #38	24 C.R. #8 1	25 #35	26 #14	27
	31 #28	32 #29	33 C.R. #6 A	34 #34	35 #18	36 #2	37 #15
W	41 #36	42 C.R. #5 4	43 #23	44 C.R. #3 C	45 #5	46 C.R. #2 2	47 #16	E
	51 #4	52 #24	53 #20	54 #22	55 C.R. #7 B	56 #6	57 #43
	61	62 #11	63 #30	64 C.R. #4 3	65 #39	66 #37	67
		72	73 #31	74 #27	75 #32	76	

S

18, 262. 64 gm. U^{235}

Fig. 2.3 SM-1 Core II - 37 Element Loading

N

		12 #17	13 #13	14 #12	15 #7	16 #21		
	21 #25	22 #41	23 #38	24 C.R. #8 1	25 #35	26 #14	27 #19	
	31 #28	32 #29	33 C.R. #6 A	34 #34	35 #18	36 #2	37 #15	
W	41 #36	42 C.R. #5 4	43 #23	44 C.R. #3 C	45 #5	46 C.R. #2 2	47 #16	E
	51 #4	52 #24	53 #20	54 #22	55 C.R. #7 B	56 #6	57 #43	
	61 #33	62 #11	63 #30	64 C.R. #4 3	65 #39	66 #37	67 #10	
		72 #40	73 #31	74 #27	75 #32	76 #9		

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22,383.92 gm. U^{235}

Fig. 2.4 SM-1 Core II - Random Loading - 45 Elements

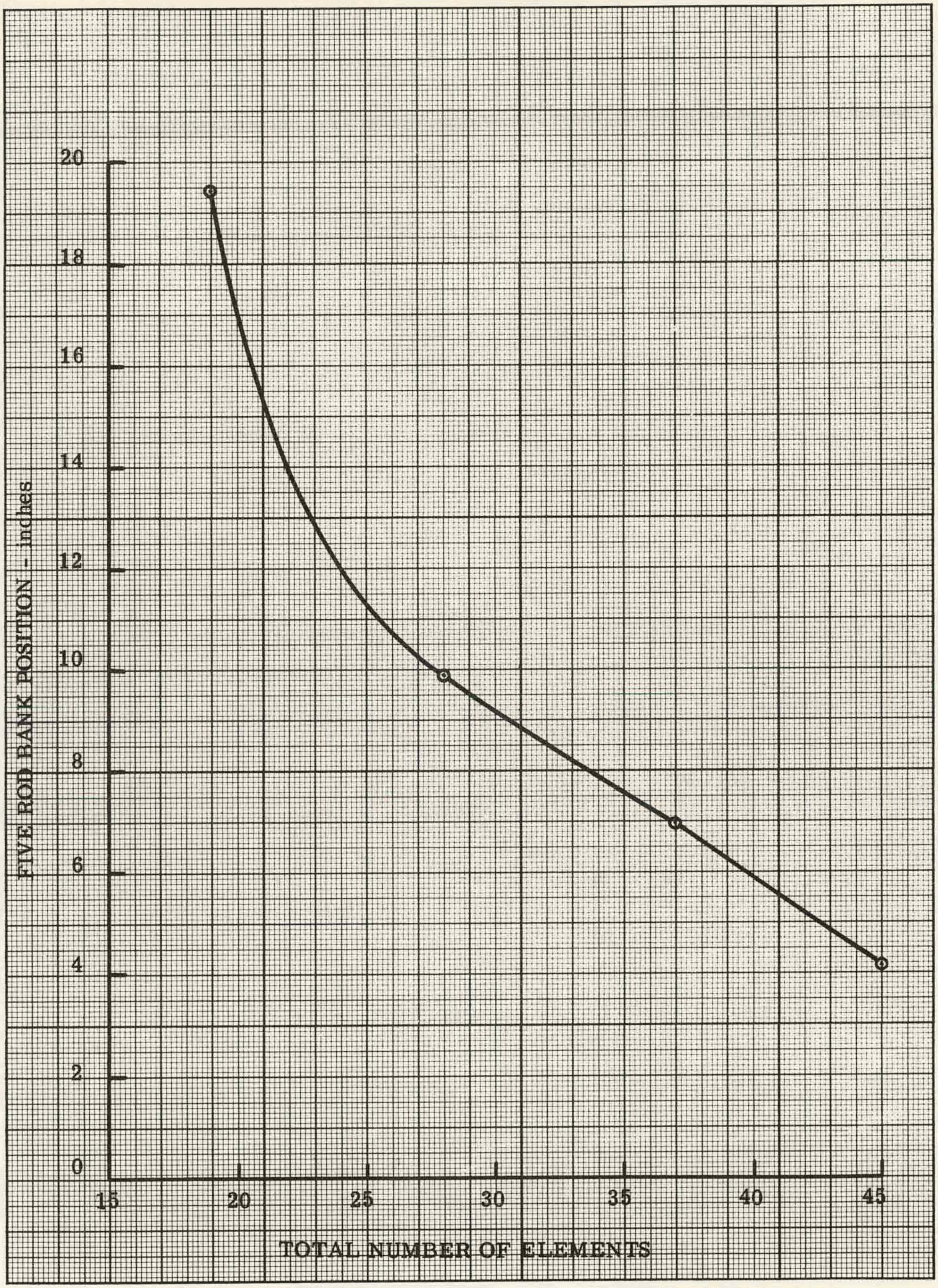

Fig. 2.5 Five Rod Bank Position vs. Number of Elements

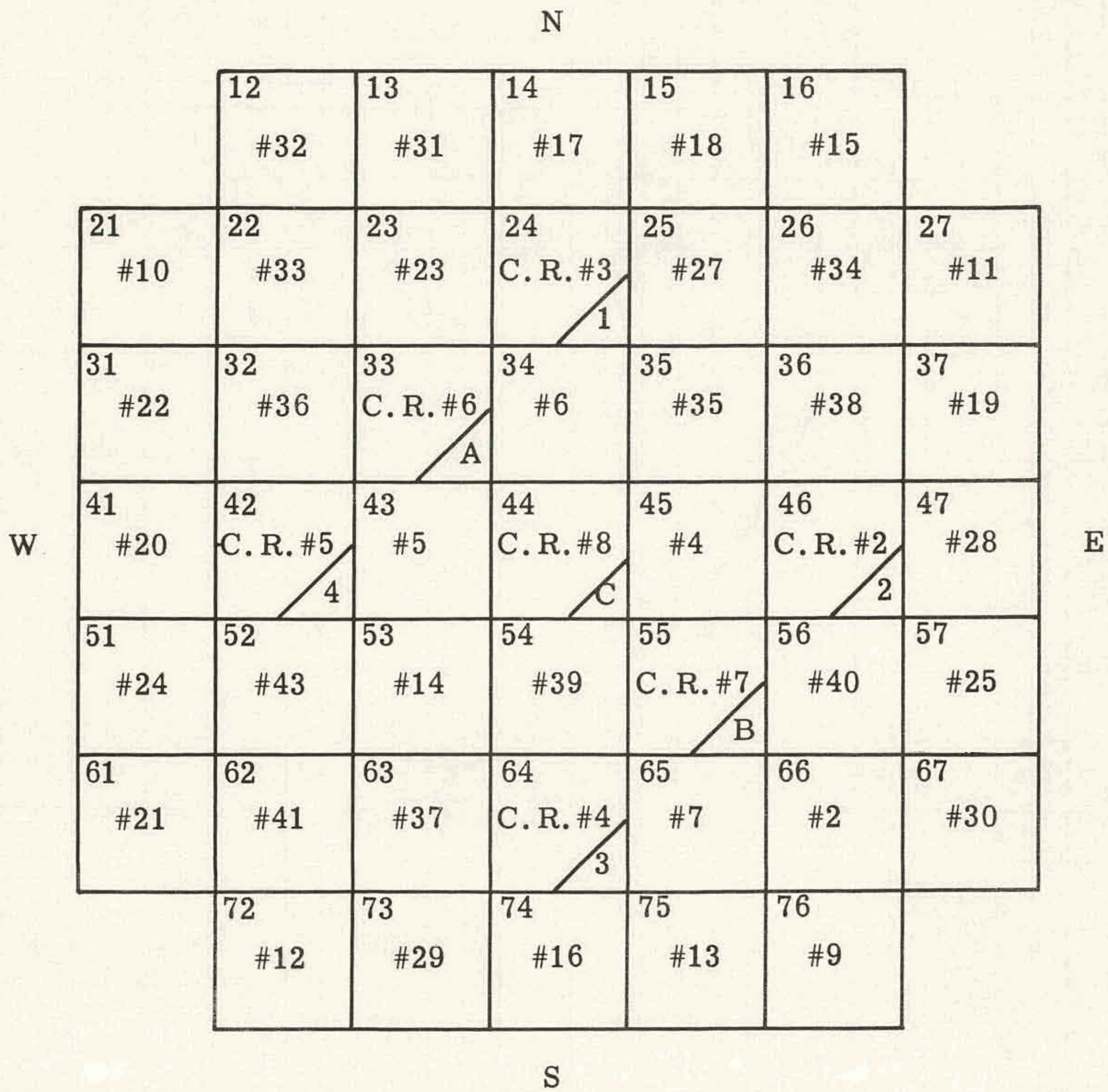

Fig. 2.6 SM-1 Core II - Loading for Minimum Reactivity Measurements

2.4.3 Maximum Reactive Core Loading

The maximum reactive core loading was assembled placing elements with highest boron loading at the outside of the core (Fig. 2.7). The five rod bank critical position and a calibration point were obtained with rods A and B at 21.763 in.

Five rod bank critical position - 3.923

Five rod bank worth - 142 cents per in. @ 3.974 in.

2.4.4 Difference Between Maximum and Minimum Reactive Core Loading

The change in five rod bank critical position from maximum reactive core to minimum reactive core was 0.410 in., or 62.3 cents. The change in reactivity from maximum to minimum reactive cores is predictable by using SM-1 boron reactivity coefficients measured in CE-1 [4] and the difference in grams of B-10 between the Core II elements and standard. Table 2.5 lists, for maximum and minimum reactive loadings, SM-1 core positions with respective boron worths, boron difference between Core II elements and the standard element in these positions, and calculated reactivity difference between Core II elements and the standard element in these positions.

TABLE 2.5
REACTIVITY DIFFERENCE BETWEEN MAXIMUM AND MINIMUM REACTIVE CORE LOADINGS

Element Position	B-10 Worth (Cents /gm B-10)	Maximum Reactive Core B-10 Diff. (gm)	Maximum Reactive Core Reactivity Diff. (Cents)	Minimum Reactive Core B-10 Diff. (gm)	Minimum Reactive Core Reactivity Diff. (Cents)
12, 16, 21, 27, 61, 72, 76, 67	40.7	+ 0.233	- 9.48	- 0.338	+ 13.76
14, 41, 47, 74	27.1	+ 0.263	- 7.13	- 0.118	+ 3.20
13, 31, 75, 57, 15, 51, 73, 37	44.4	+ 0.317	-14.07	- 0.180	+ 7.99
22, 66, 26, 62	79.9	- 0.065	+ 5.19	+ 0.154	- 12.30
23, 32, 65, 56	80.6	- 0.084	+ 6.77	+ 0.098	- 7.90
25, 36, 52, 63	74.1	- 0.079	+ 5.85	+ 0.113	- 8.37
35, 53	109	- 0.099	+10.79	+ 0.139	- 15.15
34, 43, 54, 45	86	- 0.317	+27.26	+ 0.293	- 25.20
TOTAL	-----	-----	+25.18	-----	- 43.97

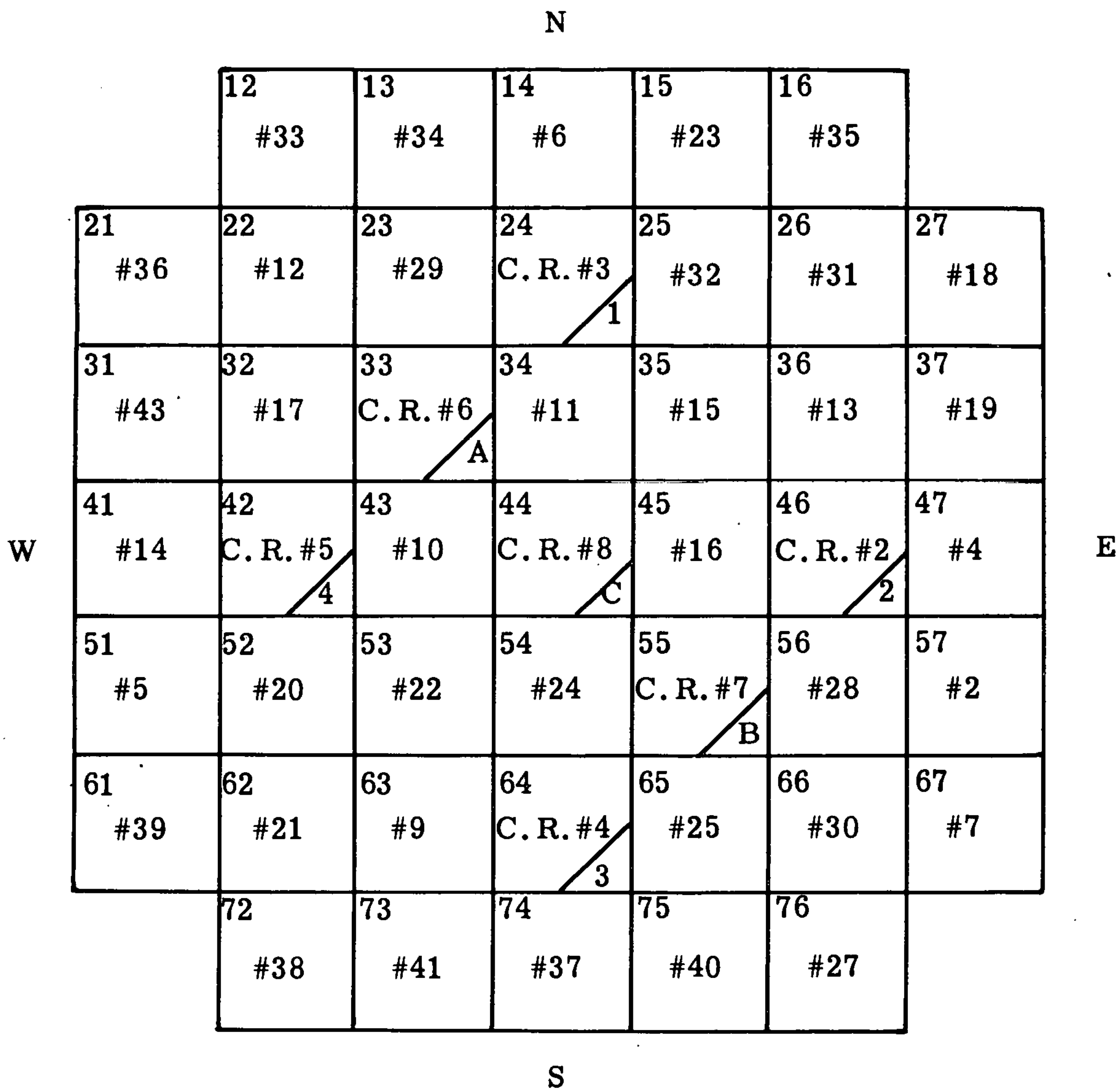

Fig. 2.7 SM-1 Core II - Loading for Maximum Reactivity Measurements

Thus, predicted reactivity change between maximum and minimum core loadings is 69.2 cents, indicating excellent agreement between the individual element uniformity check and the full core assembly tests.

2.4.5 Excess K Available

Rod worth calibration points taken on the assembled SM-1 Core II, combined with those of SM-1A Core I, yield a calibration curve similar to that obtained for SM-1 plotted in CE-1[4], displaced somewhat to the left. Areas under the curves are approximately the same, permitting use of the integrated value from CE-1, which gives an excess K of 25.40 dollars. The value for europium absorber sections would be the same, even though cold critical bank position is slightly lower with this material.

2.5 SUBSTITUTION MEASUREMENTS IN SM-1 CORE II

2.5.1 Procedures

Substitution measurements were made in support of the program to insert SM-2 elements in Core II. Measurements were also made of the effect of a water hole in various positions in Core II. Control rods 1, C, 4, A, and B were positioned as a bank, and the reactivity difference between a Core II element and a water hole or an SM-2 mockup element in that position was measured on calibrated control rods 2 and 3. All measured reactivity differences were normalized to the SM-1 standard element because of boron loading variations in Core II elements.

2.5.2 Worth of a Water Hole in SM-1 Core

Table 2.6 lists the SM-1 element positions and the worth of a water hole in these positions.

2.5.3 Worth of an SM-2 Element in SM-1 Core

Table 2.7 lists SM-1 element positions and the worth of an SM-2 mockup element in these positions.

TABLE 2.6
WORTH OF A WATER HOLE IN AN SM-1 CORE

Element Position	Water Hole Worth (cents)
12	-38.4
13	-51.7
14	-79.3
21	-37.1
22	-55.6
23	-82.1
31	-44.5
32	-79.9
34	-157.7
41	-59.2
43	-155.3

TABLE 2.7
WORTH OF AN SM-2 ELEMENT IN AN SM-1 CORE

Element Position	SM-2 Element Worth (cents)
12	-4.3
13	-6.8
14	-4.6
21	-4.7
22	-8.1
23	-5.6
31	-7.0
32	-5.3
34	-6.3
41	-5.6
43	-6.8

2.6 CONCLUSION

The random core loading five rod bank critical position, 4.153 in., differs from the value of 3.83 in. obtained in the SM-1 Core I[(7)*] and the SM-1 ZPE Core I.[(6)*] In both SM-1 Core I measurements, the core was surrounded by a steel skirt, worth about -70¢ [(5)] or 0.36 in. bank motion, giving a corrected bank position of 3.47 in. for an all-water reflector. The difference, then, between SM-1 Core I and Core II is 0.68 in.

* 0.13 in. dial correction added to original data reported in references 6 and 7.

B-10 loading of Core I stationary fuel elements was estimated in CE-1 to be 13.78 gm, and B-10 worth 60.3 cents per gm. Using this B-10 worth and the difference in bank positions between Cores I and II, the B-10 loading of the stationary elements is 15.22 gm compared with 13.96 gm of the standard element comparison.

This may be due to any of the following, in the order of estimated importance:

1. Effect of integral flux suppressors in the control rod fuel elements.

2. Error in estimated SM-1 standard B-10 content.

3. A random loading of the fuel elements may not have been used in the Core I and ZPE Core I measurements.

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3.0 FLUX MEASUREMENTS

3.1 INTRODUCTION

Flux measurements in the SM-1 Core II zero power experiment were made with two specific objectives:

1. Determination of power peaking in the region of the control rod absorber-control rod fuel element interface.

2. Determination of power peaking in the region of the core-reflector interface. The measurements were divided:

   (a) side reflector-core interface measurements.

   (b) bottom reflector-core interface measurements.
   Fission foils were used for all the flux measurements so that the power distribution would be directly proportional to the measured flux distribution.

3.2 EXPERIMENTAL TECHNIQUE AND NOMENCLATURE

Fission foils of 0.25 in. dia, used throughout the experiment, were taped directly to exterior fuel plates; however, for internal measurements, the foils were taped to plexiglass stringers inserted between the interior fuel plates. The stringers were sufficiently thick to place the foils in contact with the plates. The foil centers were positioned to $\pm$ 0.06 in., except for those placed in the absorber section, which were positioned by extending the stringers from the control rod fuel elements. These stringers, supported by compressed springs, tended to tilt slightly, hence the lateral positions of the foils placed within the absorber sections have a probable error of $\pm$ 0.10 in.

The following nomenclature is used in this chapter to accurately define foil locations:

Position	-	Location of foil measured from the bottom of the active core in inches.
Axial plane	-	Plane perpendicular to the core axis and measured from the bottom of the active core in inches.

Radial plane	-	Plane parallel to the north-south plane of the core, measured from the central radial plane.
Central radial plane	-	Plane parallel to the north-south plane of the core and passing through the core centerline.

Figure 3.1 shows locations of various radial planes, west side of core; these planes are perpendicular to the plane of the figure. In the following tables, W. R. P. stands for west radial plane; E. R. P. stands for east radial plane. Figure 3.2 shows fuel plate notation used in this report. The fuel plates were denoted alphabetically, starting with a on the north side of the fuel element. In the tables, it is noted whether the foils were put on the north or south side of the fuel plates.

All activities reported are normalized relative to the activity of a fission foil placed on the south side of plate r of the fuel element in position number 53, in the central radial plane and the 2.875 in. axial plane.

The word "flux" is used interchangeably with the words "activity" or "relative activity", since the flux is directly proportional to foil activity, and no absolute flux values were obtained.

3.3 EXPERIMENTAL DATA

3.3.1 Control Rods

Table 3.1 is a tabulation of flux measurements made within control rod "C". The table gives the three coordinates necessary to exactly specify the position of each foil: plate number, position above bottom of active core, and radial plane within which it lies. In addition, the side of the plate on which it was placed is indicated. The seven rod bank was withdrawn to 6.249 in. for these measurements. Table 3.2 presents the flux measurements made within control rod 1. During these and succeeding flux measurements, the five rod bank was withdrawn 4.162 in. and control rods A and B were fully withdrawn. Tables 3.3 and 3.4 are tabulations of flux data taken in stationary elements around control rod elements C and 1. Figure 3.3 lists the fuel plate dimensions and shows the location of the active meat and the suppressor section.

3.3.2 Reflector Flux Peaking

Tables 3.5 and 3.6 present foil activation data taken to determine bottom and side reflector flux peaking; however, all data tabulated contributes to the overall reflector peaking picture.

TABLE 3.1
AXIAL FLUX TRAVERSES* - CONTROL ROD C
7 Rod Bank at 6.249 Inches

Position From Bottom of Active Core, Inches	Plate A North Side 1.125 WRP	Plate A North Side 0.125 ERP	Plate A North Side 1.125 ERP	Plate P South Side 0.125 ERP	Plate B South Side 0.125 ERP	Plate G South Side 0.125 ERP	Plate N South Side 0.125 ERP	Plate B South Side 1.125 ERP	Plate G South Side 0.75 WRP	Plate G North Side 0.75 ERP
8.889					0.65	2.00	1.32		1.39	1.33
7.905					0.96	2.88	1.81		1.90	1.95
6.905					1.93	2.72	2.28	2.00	2.40	2.41
6.624	1.35	1.35	1.33	1.47	1.54	1.91	1.75	1.72	1.82	1.78
5.811	0.72	0.44	0.80	0.46	0.27	0.25	0.28	0.60	0.31	0.32
5.374	1.09	0.76	1.12	0.68	0.52	0.44	0.53	0.70	0.60	0.53
4.936	1.32	0.99	1.32	1.05	0.93	0.89	0.92	1.24	1.03	0.93
4.436	1.43	1.09	1.44	1.13	1.04	0.97	1.07	1.34	1.10	1.05
3.436	1.44	1.15	1.50	1.21	1.06	1.05	1.11	1.36	1.19	1.16

* Activities normalized to reference foil in fuel element position 53, center line of plate "r", 2.875" axial plane.

TABLE 3.2
AXIAL FLUX TRAVERSES* - CONTROL ROD 1
5 Rod Bank at 4.162 Inches

Position From Bottom of Active Core, Inches	Plate A North Side 1.125 WRP	Plate A North Side 0.125 ERP	Plate A North Side 1.125 ERP	Plate P South Side 0.125 ERP	Plate B South Side 0.125 ERP	Plate G South Side 0.125 ERP	Plate N South Side 0.125 ERP	Plate B South Side 1.125 ERP	Plate G South Side 0.75 WRP	Plate G North Side 0.75 ERP
6.802					1.26	3.03	1.55		2.19	2.03
5.818					1.54	3.75	1.93		2.48	2.51
4.818					2.24	3.28	2.64	1.88	2.79	2.75
4.537	1.46	1.49	1.38	1.74	1.76	2.25	2.05	1.50	2.12	2.04
3.724	0.69	0.39	0.71	0.47	0.25	0.24	0.30	0.61	0.37	0.28
3.287	0.91	0.59	0.90	0.69	0.47	0.39	0.55	0.55	0.51	0.42
2.849	1.05	0.76	0.99	0.90	0.72	0.72	0.86	1.02	0.82	0.72
2.349	1.02	0.77	0.99	0.97	0.76	0.73	0.88	0.93	0.82	0.78
1.349	0.92	0.72	0.90	0.93	0.72	0.72	0.78	0.81	0.79	0.76

* Activities normalized to reference foil in fuel element position 53, center line of plate "r", 2.875" axial plane.

TABLE 3.3

AXIAL FLUX TRAVERSES* - ELEMENT POSITIONS 14, 23 AND 25

5 Rod Bank at 4.162 Inches

		Element Position 14			Element Position 23	Element Position 25
Position From Bottom of Active Core, Inches	Plate R South Side 1.125 WRP	Plate R South Side 0.125 ERP	Plate R South Side 1.125 ERP	Plate H South Side 0.125 ERP	Plate H South Side 2.813 WRP	Plate H South Side 3.063 ERP
18.00		0.20		0.31	0.37	0.50
14.00		0.31		0.51	0.64	0.78
10.00		0.40		0.66	0.88	0.96
6.77	0.74	0.44	0.58	0.71	0.96	1.07
5.80	0.91	0.61	0.71	0.72	0.96	1.07
4.50	1.12	0.92	1.03	0.75	1.01	1.09
3.65	0.96	0.70	0.92	0.69	0.90	1.06
3.25	0.98	0.75	0.95	0.68	0.93	1.04
2.79	1.00	0.82	0.94	0.69	0.91	0.94
2.28	0.97	0.82	0.95	0.66	0.89	0.90
1.26		0.73		0.57	0.81	0.82
0		1.17		1.12	1.77	1.63
-.5		1.42		1.54	2.43	2.14

* Activities normalized to reference foil in fuel element position 53, center line of plate "r", 2.875" axial plane.

TABLE 3.4

AXIAL FLUX TRAVERSES* - ELEMENT POSITION 34

5 Rod Bank at 4.162 Inches

Position From Bottom of Active Core, Inches	Plate A North Side 1.125 WRP	Plate A North Side 0.125 ERP	Plate A North Side 1.125 ERP	Plate R South Side 1.125 WRP	Plate R South Side 0.125 ERP	Plate R South Side 1.125 ERP	Plate H South Side 0.125 ERP
18.00		0.19			0.18		0.39
14.00		0.35			0.34		0.70
10.00		0.49			0.47		0.97
6.77	0.95	0.62	0.81	0.84	0.53	0.91	1.12
5.80	1.13	0.71	1.00	0.94	0.68	1.04	1.14
4.50	1.44	1.13	1.39	1.48	1.26	1.46	1.21
3.65	1.31	0.91	1.13	1.24	0.91	1.28	1.27
3.25	1.41	0.97	1.22	1.25	1.02	1.38	1.17
2.79	1.42	1.08	1.28	1.33	1.15	1.41	1.16
2.28	1.36	1.07	1.23	1.38	1.16	1.45	1.11
1.26		1.00			1.09		1.06
0		1.61			1.77		2.12
-.5		1.86			2.08		3.05

* Activities normalized to reference foil in fuel element position 53, center line of plate "r", 2.875" axial plane.

TABLE 3.5
AXIAL FLUX TRAVERSES* - BOTTOM REFLECTOR PEAKING
5 Rod Bank at 4.162 Inches

Position From Bottom of Active Core, Inches	Element Position 12 Plate H South Side 5.750WRP	Element Position 12 Plate +H South Side 7.345 WRP	Element Position 12 Plate A North Side 5.750 WRP	Element Position 13 Plate H South Side 2.813 WRP	Element Position 21 Plate H South Side 8.688 WRP	Element Position 21 Plate A North Side 8.688 WRP	Element Position 43 Plate H South Side 2.813 WRP	Element Position 41 Plate H South Side 8.688 WRP	Element Position 32 Plate H South Side 5.750 WRP	Element Position 31 Plate H South Side 8.688 WRP	Element Position 22 Plate H South Side 5.750 WRP
-1.00	1.40	1.15	1.07	1.81	1.37	1.15	3.67	1.88	2.80	1.79	2.26
-0.50	1.22	1.19	1.08	1.51	1.19	1.28	2.99	1.50	2.34	1.46	1.77
0.00	0.88	1.17	0.90	1.14	0.93	1.26	2.08	1.06	1.65	1.14	1.38
1.00	0.37	1.08	0.66	0.47	0.36	0.74	0.91	0.50	0.71	0.47	0.60
3.00	0.48	1.48	0.86	0.61	0.46	1.01	1.07	0.59	0.91	0.57	0.77
5.00	0.58	1.77	1.06	0.74	0.58	1.22	1.12	0.62	0.97	0.68	0.87
7.00	0.63	1.90	1.25	0.75	0.64	1.32	1.32	0.63	1.00	0.71	0.92

* Activities normalized to reference foil in fuel element position 53, center line of plate "r", 2.875" axial plane.
\+ Foil placed on side plate in line with plate H.

TABLE 3.6
AXIAL FLUX TRAVERSES* - SIDE REFLECTOR PEAKING
5 Rod Bank at 4.162 Inches

Position From Bottom of Active Core, Inches	Element Position 41 Plate A North Side 10.053 WRP	Element Position 41 Plate A North Side 9.428 WRP	Element Position 41 Plate A North Side 8.688 WRP	Element Position 41 Plate A North Side 7.573 WRP	Element Position 14 Plate A North Side 0.125 ERP	Element Position 14 Plate C South Side 0.125 ERP	Element Position 14 Plate M South Side 0.125 ERP	Element Position 21 Plate A North Side 10.053 WRP	Element Position 21 Plate H South Side 10.053 WRP	Element Position 21 Plate H South Side 7.573 WRP
-1.00	1.32	1.45	1.65	1.50	1.56	1.70	2.04	1.00	1.10	1.34
0.00	1.22	1.01	1.09	1.21	1.49	0.93	1.30	1.06	0.90	1.12
3.00	1.14	0.60	0.61	0.98	1.23	0.76	0.72	1.31	0.88	0.79
7.00	1.35	0.68	0.63	0.80	1.38	0.85	0.70	1.58	1.15	0.93
12.00	1.17	0.59	0.53	0.66	1.31	0.70	0.57	1.44	0.95	0.78
18.00	0.65	0.30	0.28	0.35	0.71	0.38	0.30	0.76	0.47	0.45

* Activities normalized to reference foil in fuel element position 53, center line of plate "r", 2.875" axial plane.

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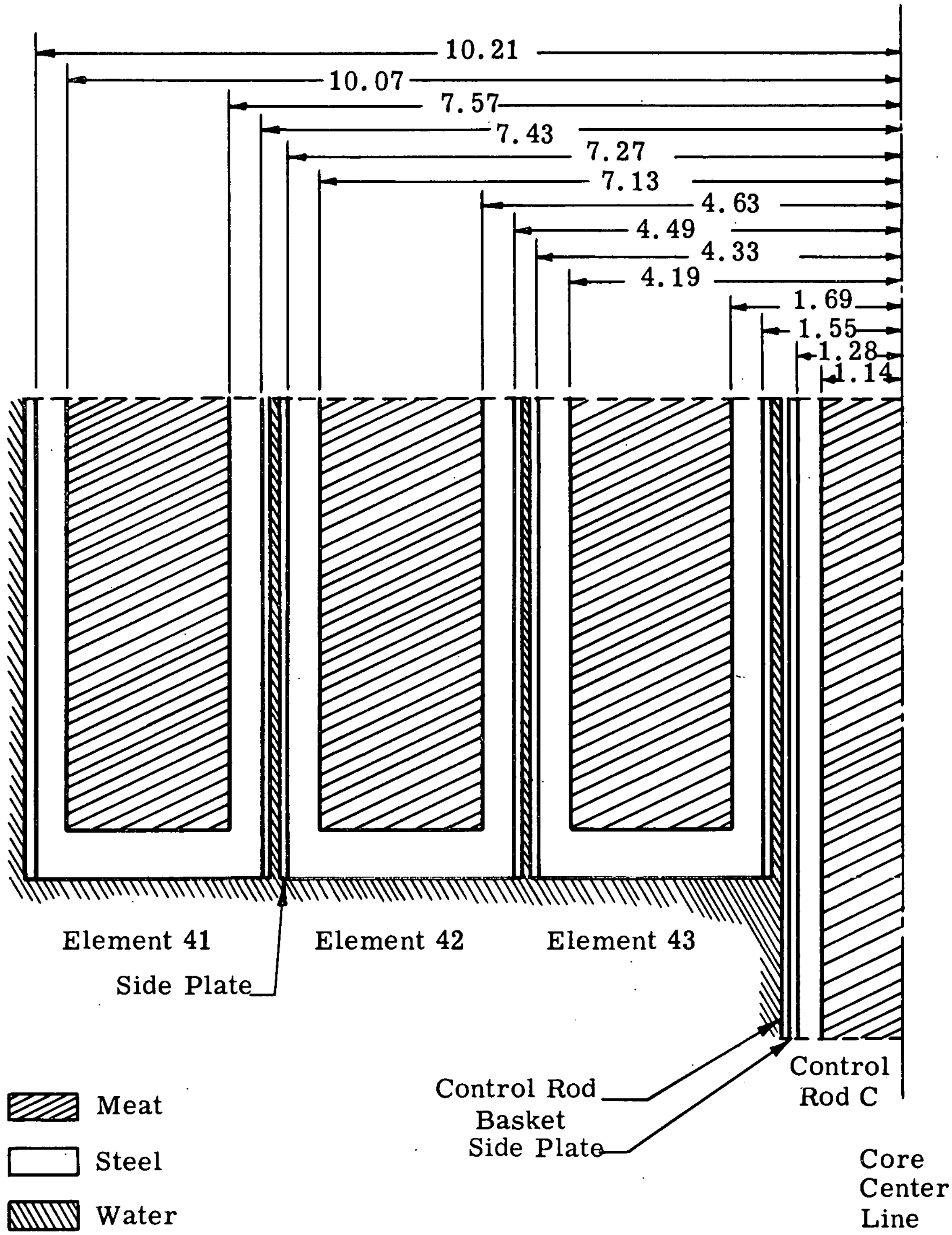
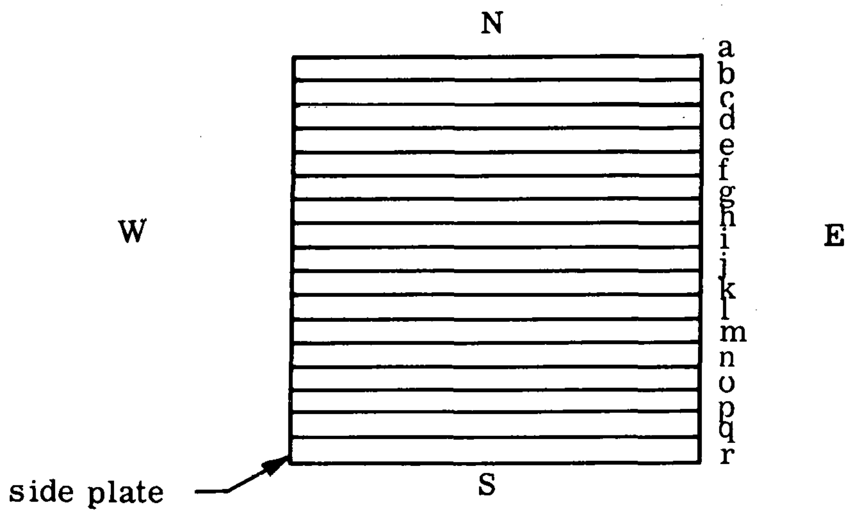


Fig. 3.1 Location of Radial Planes

Stationary Element



Control Rod Element

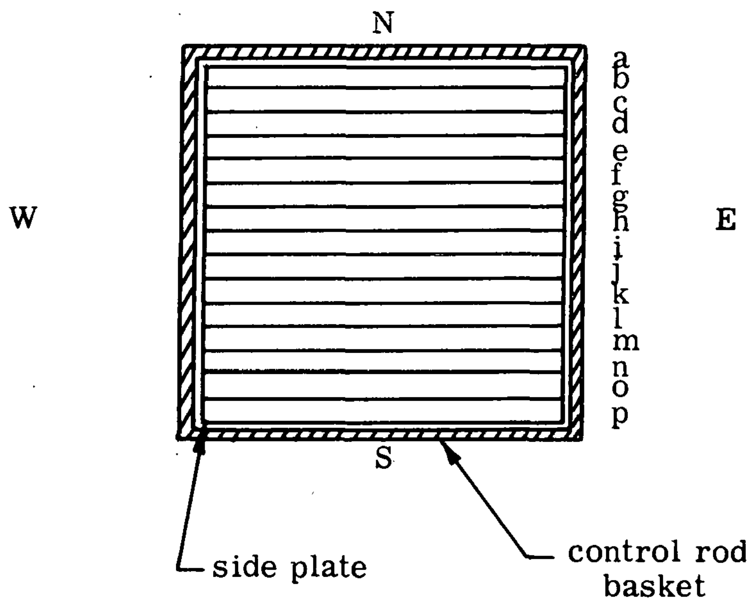


Fig. 3.2 Fuel Element Notation

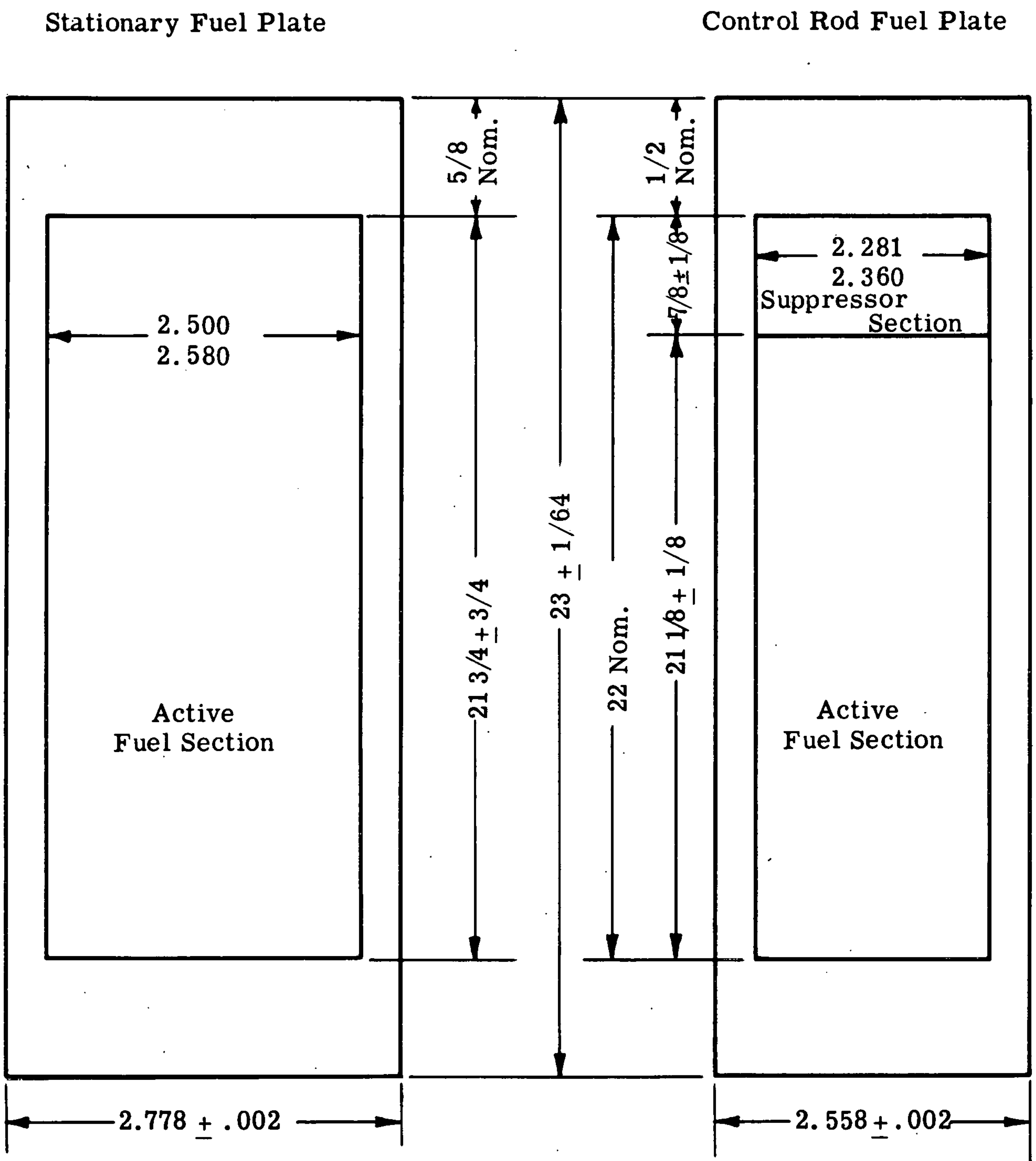


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Fig. 3.3 Fuel Plate Dimensions

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3.4 DISCUSSION OF RESULTS

Figures 3.4 and 3.5 show the effects of the europium suppressors in control rods C and 1. The neutron flux streaming from the absorber water hole is depressed strongly in the region of the suppressor. The axial flux distribution obtained in control rod C during ZPE-2 experiment was plotted as a comparison in dashed lines in Fig. 3.4. An absolute comparison cannot be made, since gold foils were used for ZPE-2 measurements and control rod positions were different; however, qualitatively, the effectiveness of europium suppressor is clearly shown. The ZPE-2 measurements are so plotted in Fig. 3.4 that the flux measurement taken at the upper edge of the fuel plate meat lines up with the flux measurement taken at the upper edge of the suppressor during the Core II experiment. The ZPE-2 flux plot was n normalized to the Core II measurements at the 3.87 in. axial plane.

Figure 3.6 shows radial flux traverses through control rod 1 at three different axial planes. These curves show the effectiveness of the Eu suppressor, and the side reflector flux peaking in element number 14. Since flux measurements in the stationary elements were not made in the same axial plane as flux measurements in control rod 1, the flux points plotted in Figure 3.6 in the stationary elements are interpolated points from axial flux plots of stationary elements 14 and 34.

Figure 3.7 presents the axial flux traverse in element position 34. Since element 34 is adjacent to control rods 1, C, and A, axial traverses of the outer fuel plates a and r show the effects of the suppressor and water hole regions. The axial flux traverse of plate h, almost in the center of the element and removed from control rods, shows less defined effects of the suppressor and water hole regions. Figures 3.8 and 3.9 exhibit axial traverses in element 14. Element position 14 is adjacent to control rod 1. Since only fuel plate r is directly adjacent to control 1, it is the only fuel plate whose axial flux traverse shows pronounced effects of the suppressor and water hole regions. The axial flux traverse of plate a, adjacent to the side reflector, is fairly flat.

Figures 3.10, 3.11 and 3.12 present curves of axial flux traverses showing flux peaking at the bottom core-reflector interface. Foil locations were such that control rod effects were very small; however, axial flux traverses of plate a, element positions 12 and 21, show the effect of the side reflector in that the curves are flatter. In general, inner fuel plates of an element exhibit greatest flux peaking at the bottom of the reactor core.

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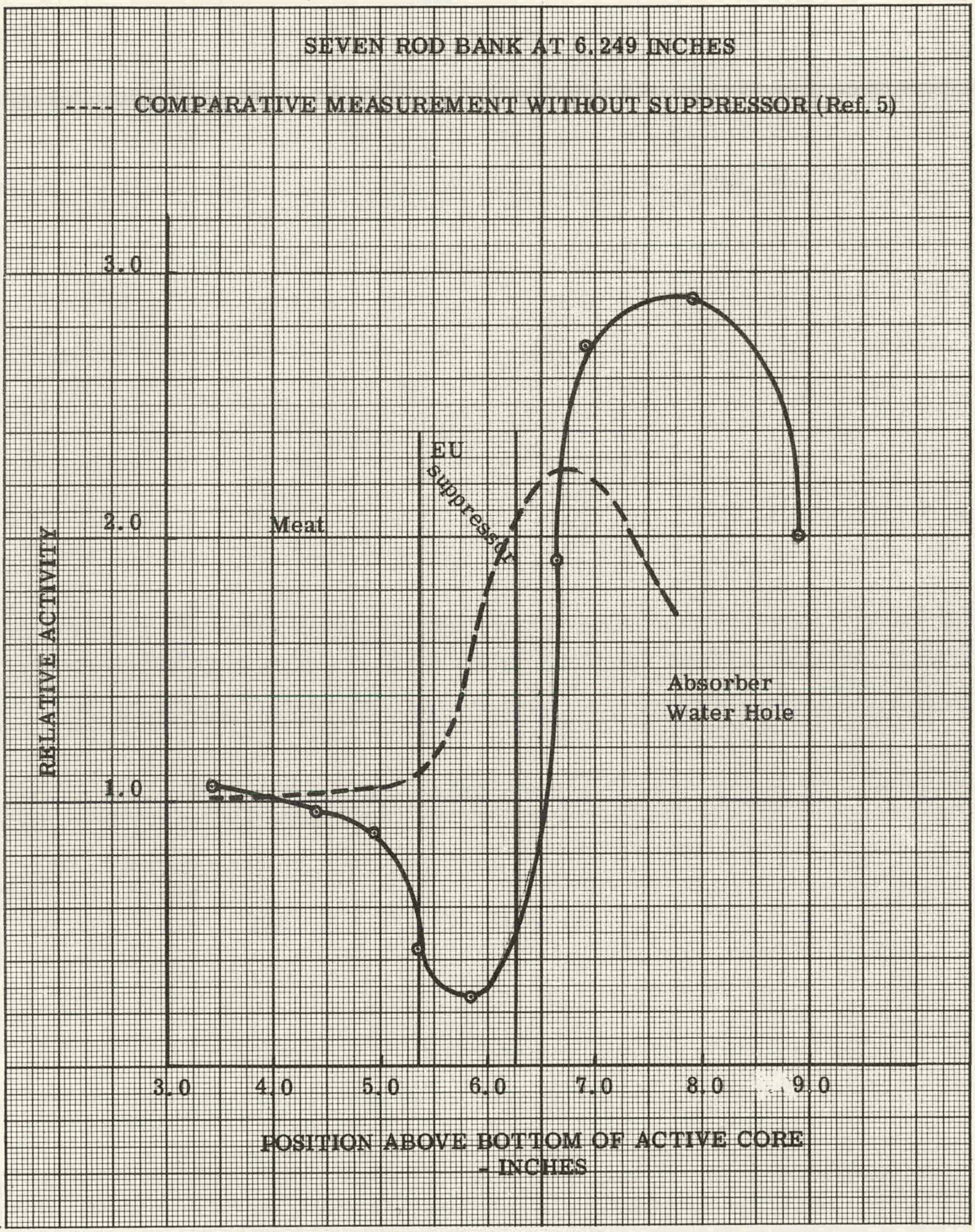

Fig. 3.4 Relative Activity vs. Axial Position in Control Rod C - SM-1 Core II Plate g - 0.125 ERP

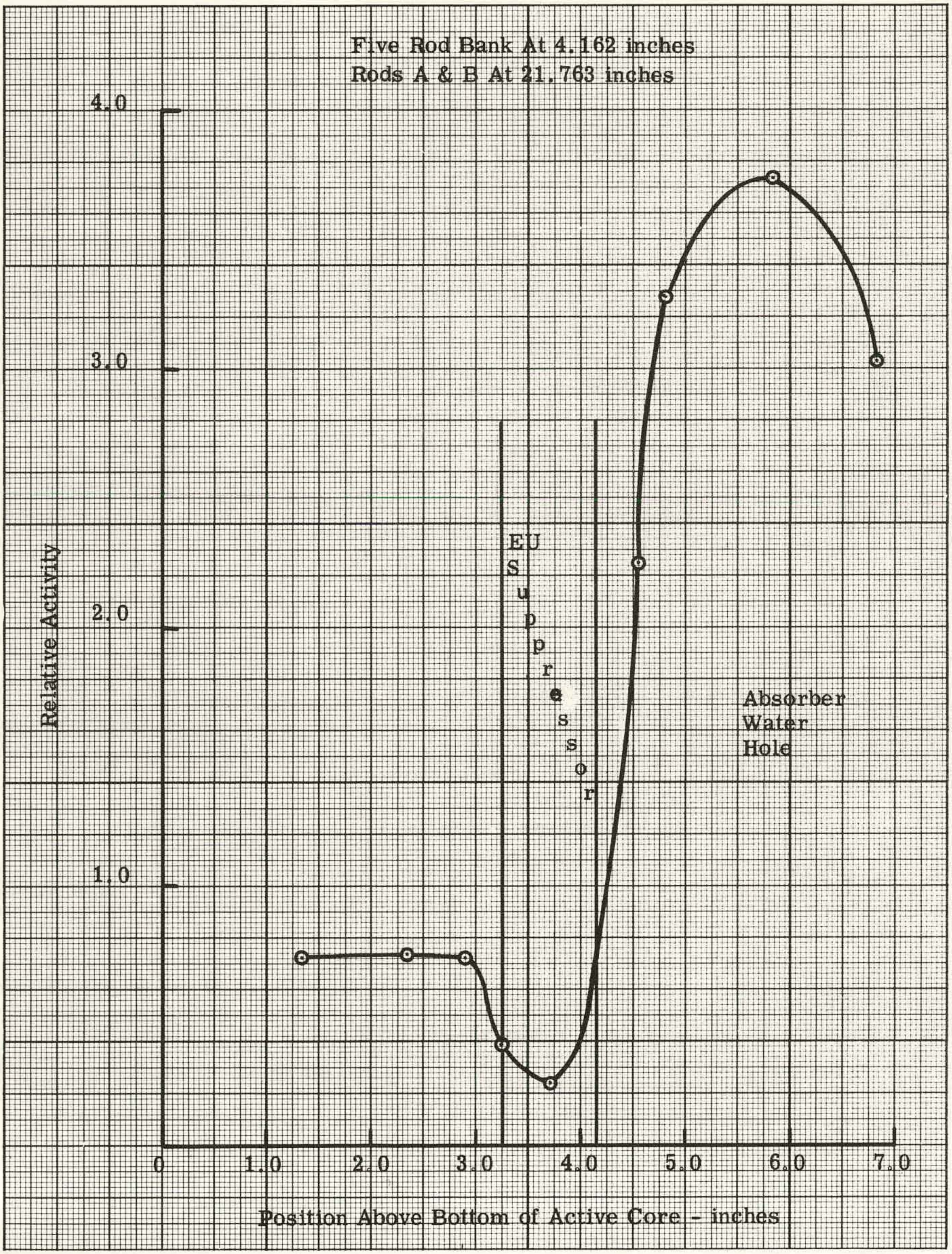

Fig. 3.5 Relative Activity vs. Axial Position in Control Rod 1 - SM-1 Core II Plate g - 0.125 ERP

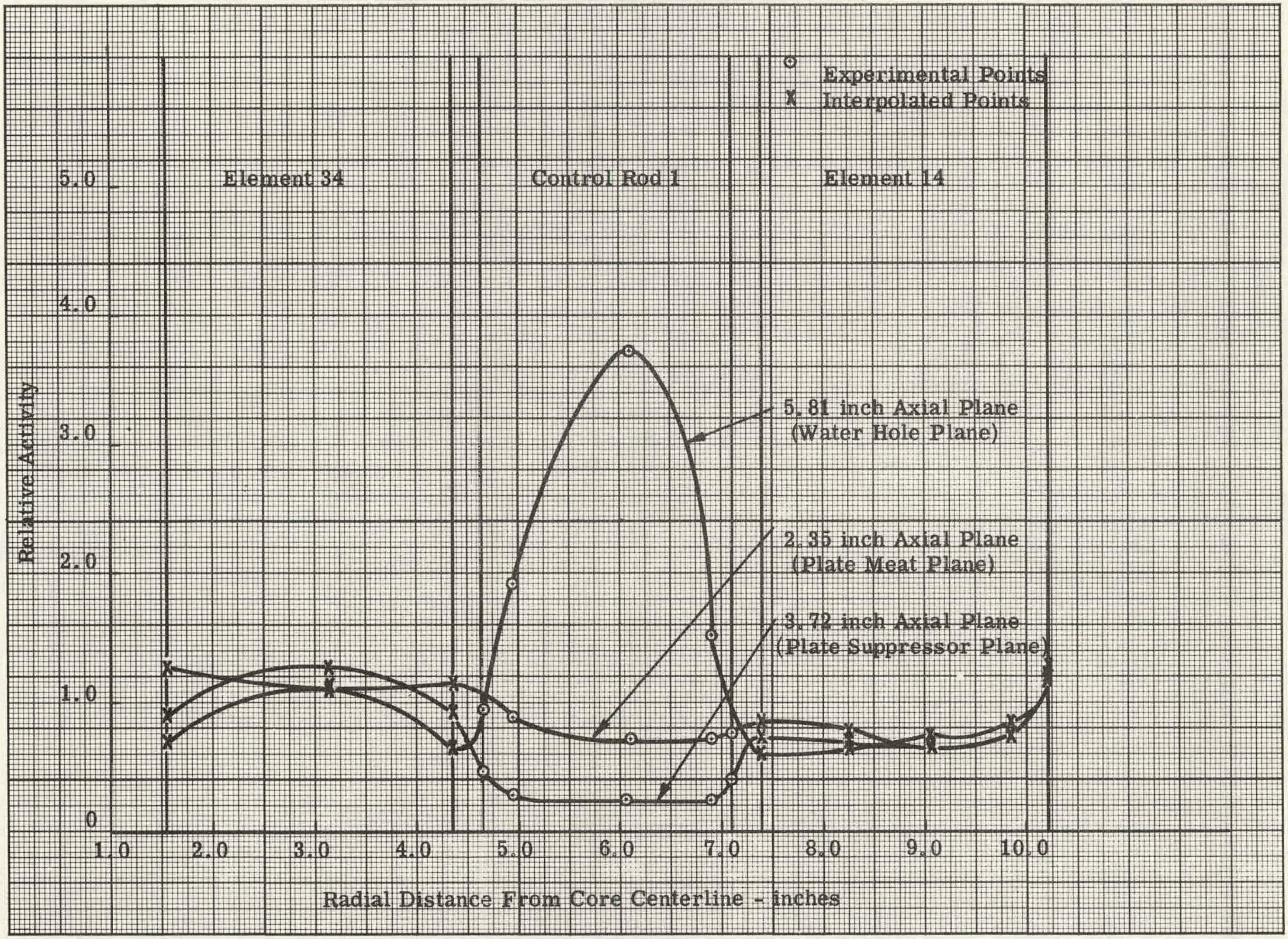

Fig. 3.6 Relative Activity vs. Radial Position through Control Rod 1 - SM-1 Core II - 0.125 ERP

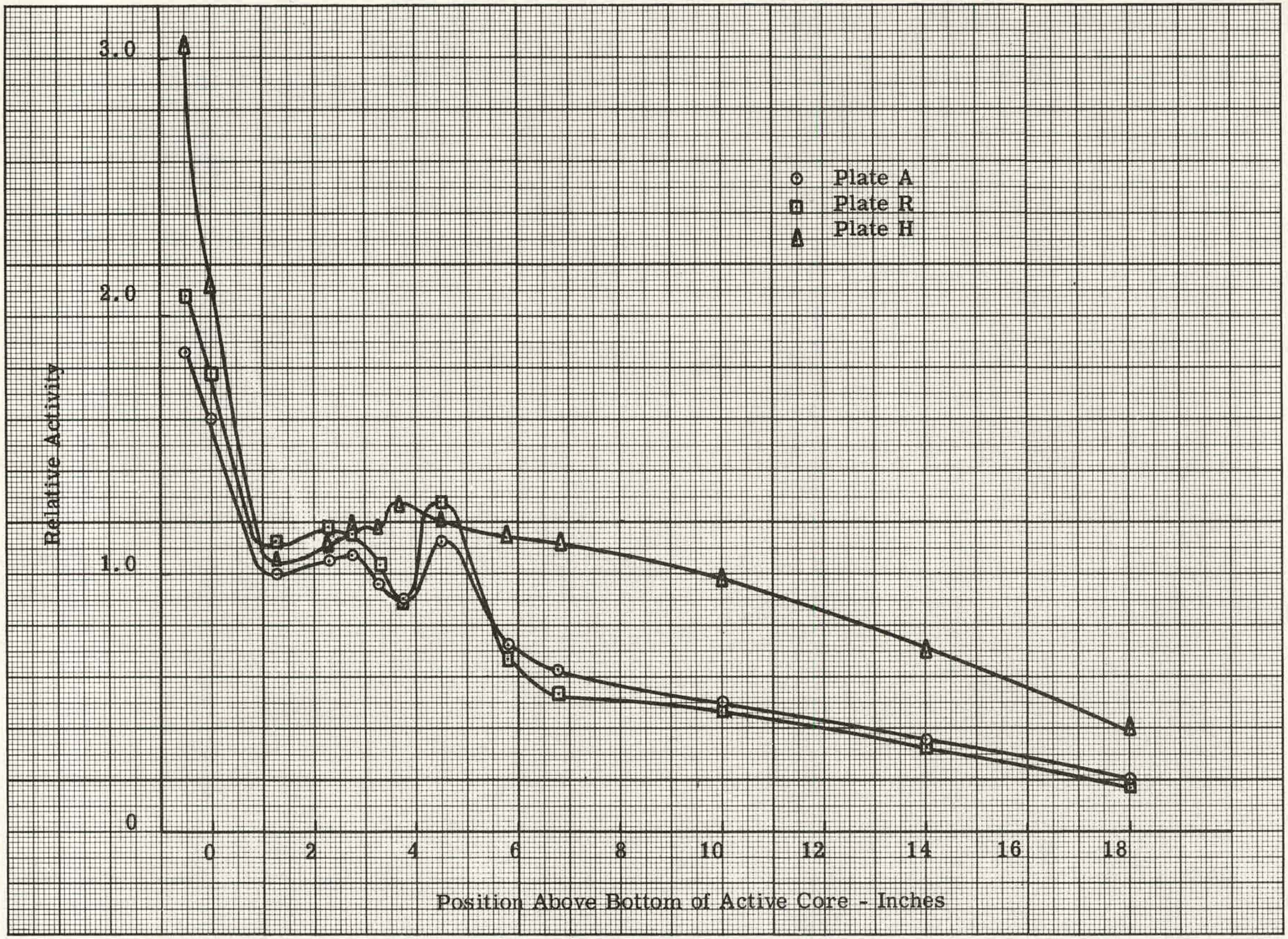

Fig. 3.7 Relative Activity vs. Axial Position in Element Position 34 - SM-1 Core II - 0.125 ERP

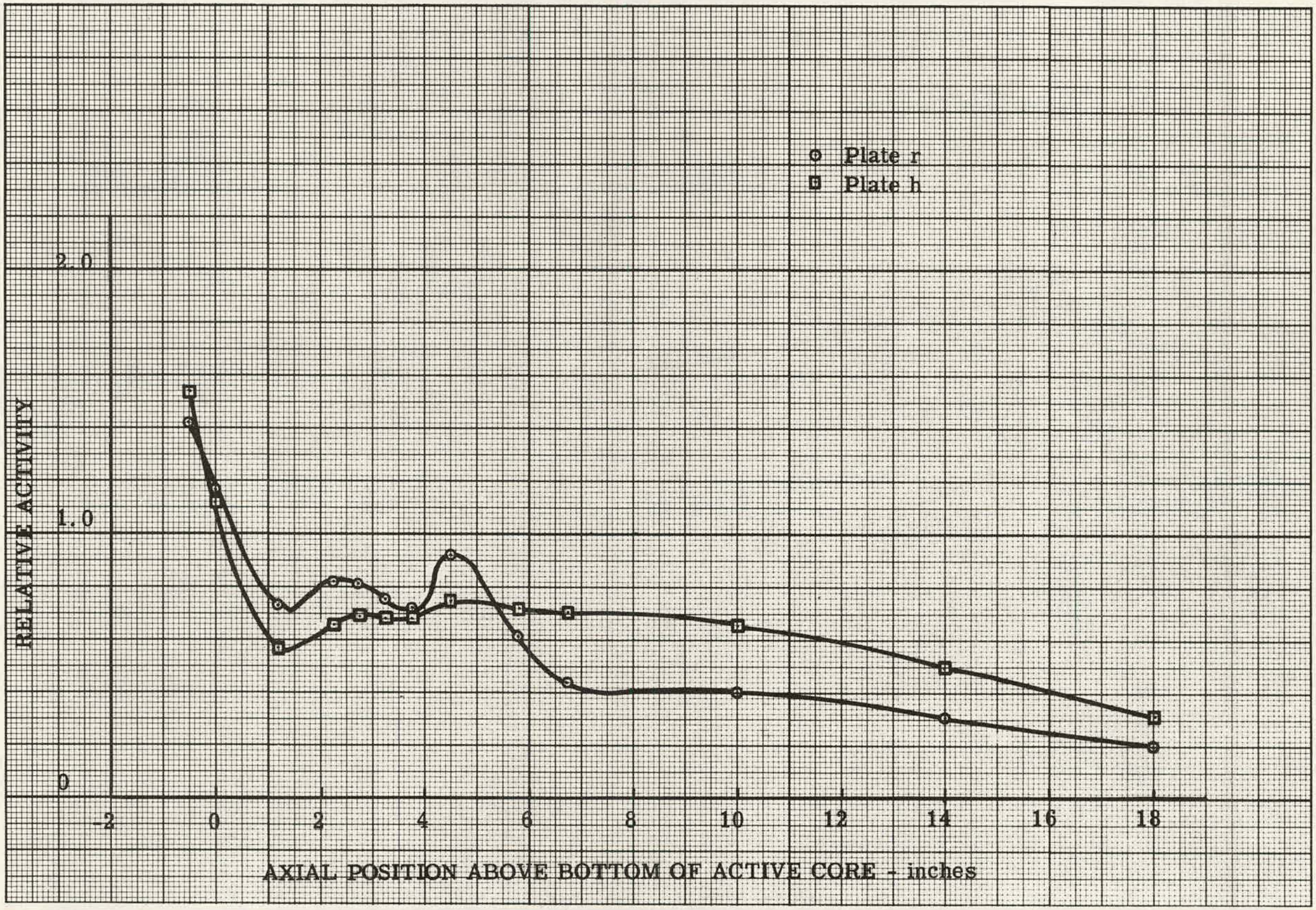

Fig. 3.8 Relative Activity vs. Axial Position in Element Position 14 - SM-1 Core II - 0.125 ERP

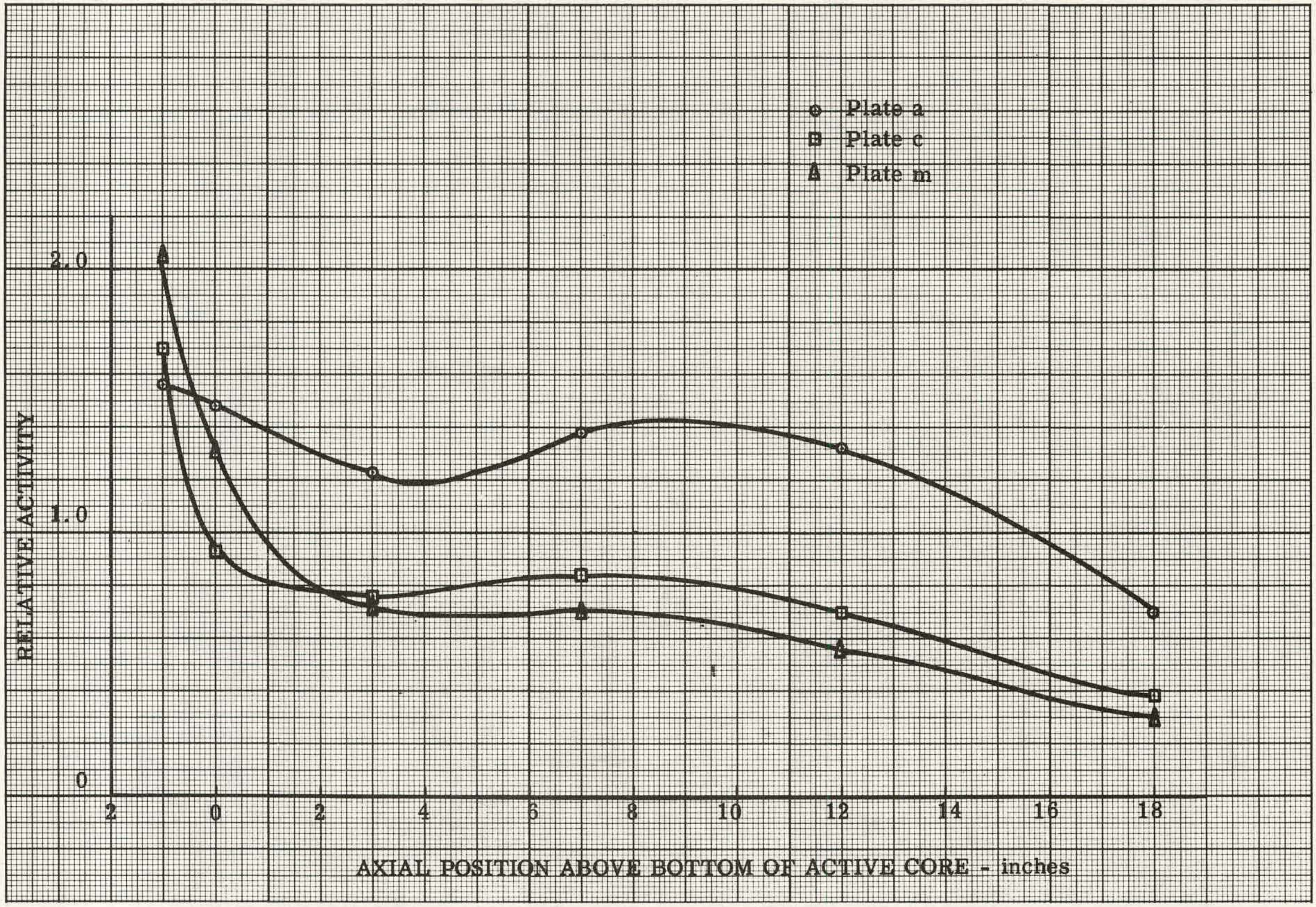

Fig. 3.9 Relative Activity vs. Axial Position in Element Position 14 - SM-1 Core II - 0.125 ERP

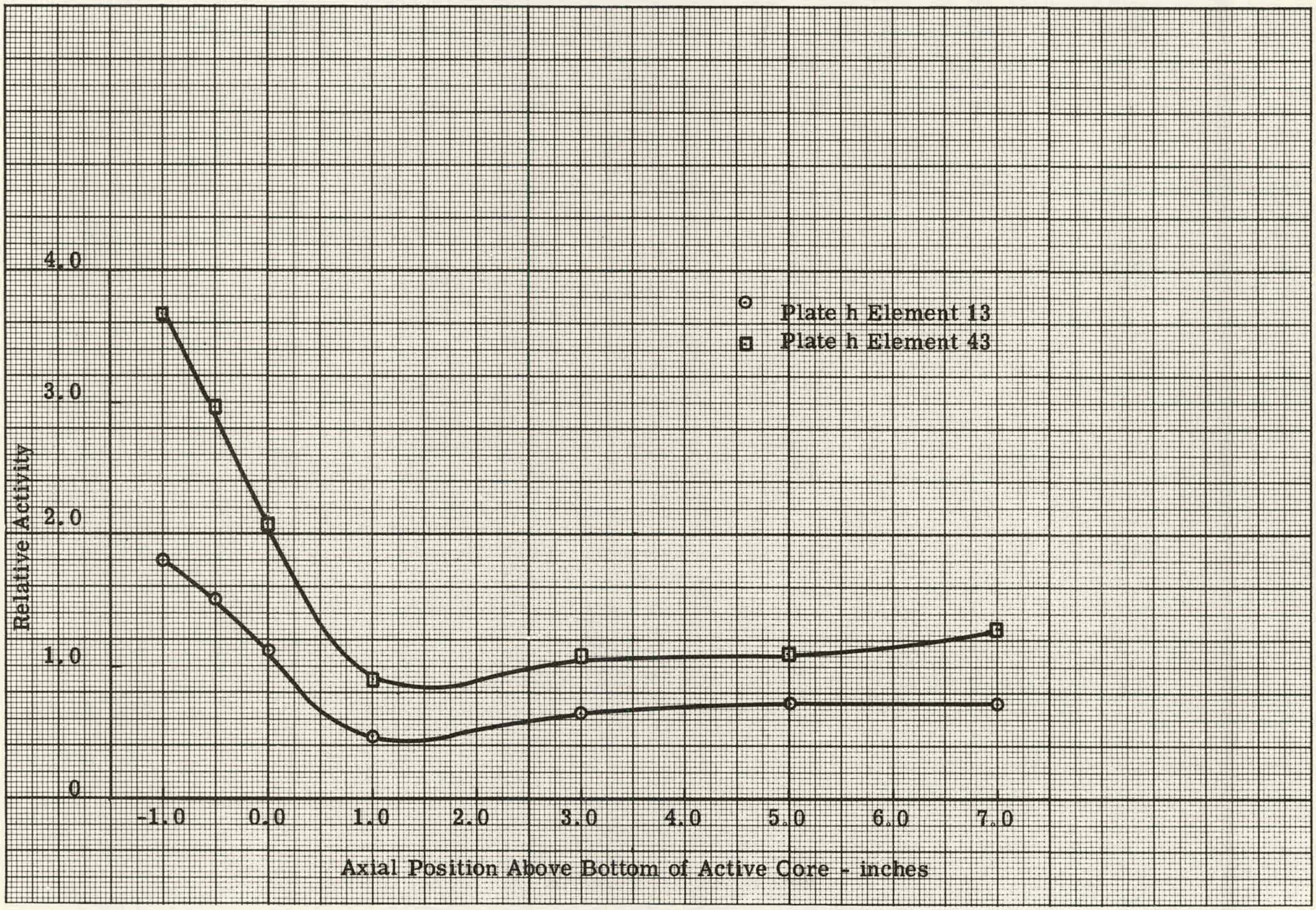

Fig. 3.10 Relative Activity vs. Axial Position - SM-1 Core II - 2.81 WRP

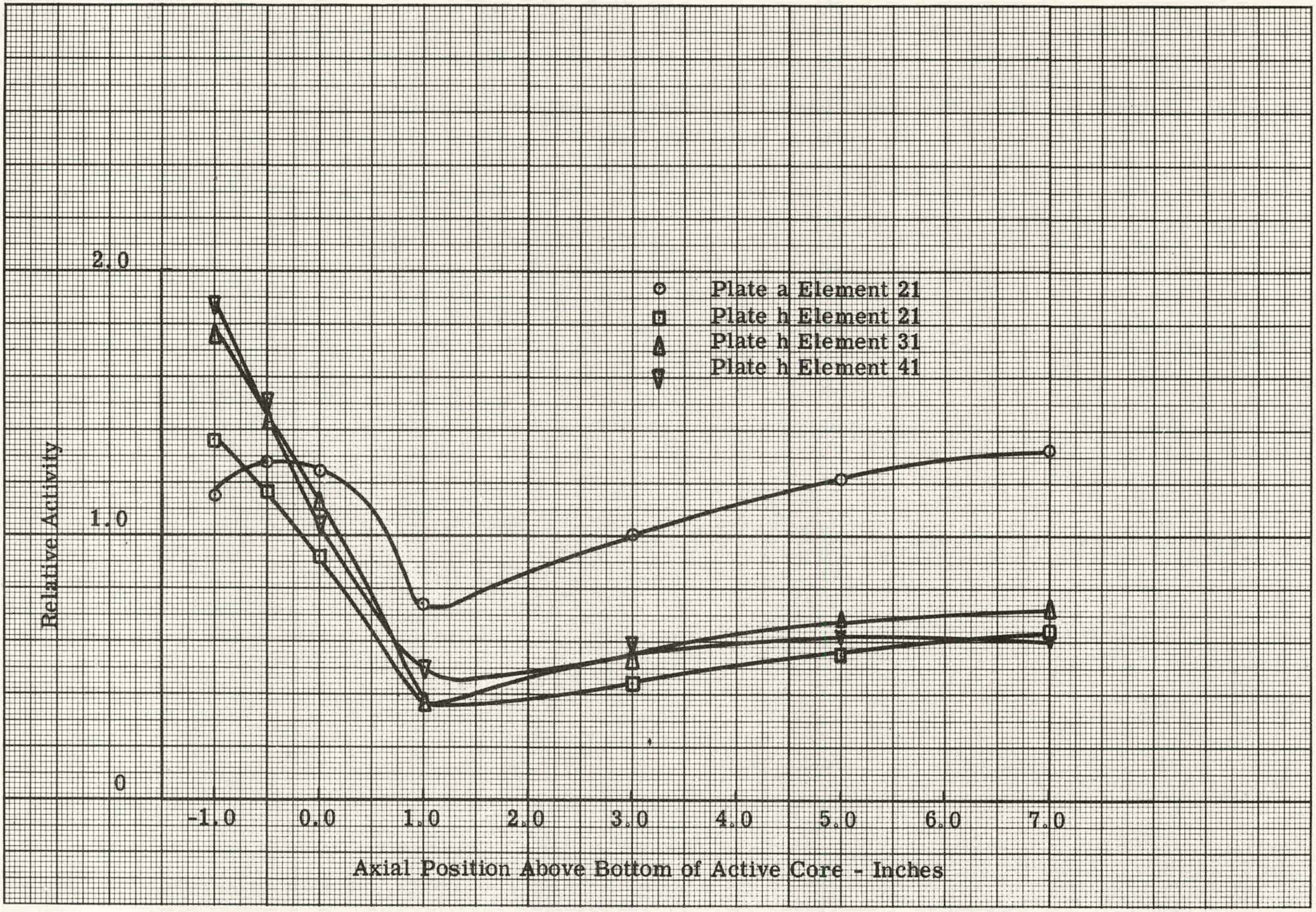

Fig. 3.11 Relative Activity vs. Axial Position - SM-1
Core II - 8.688 WRP

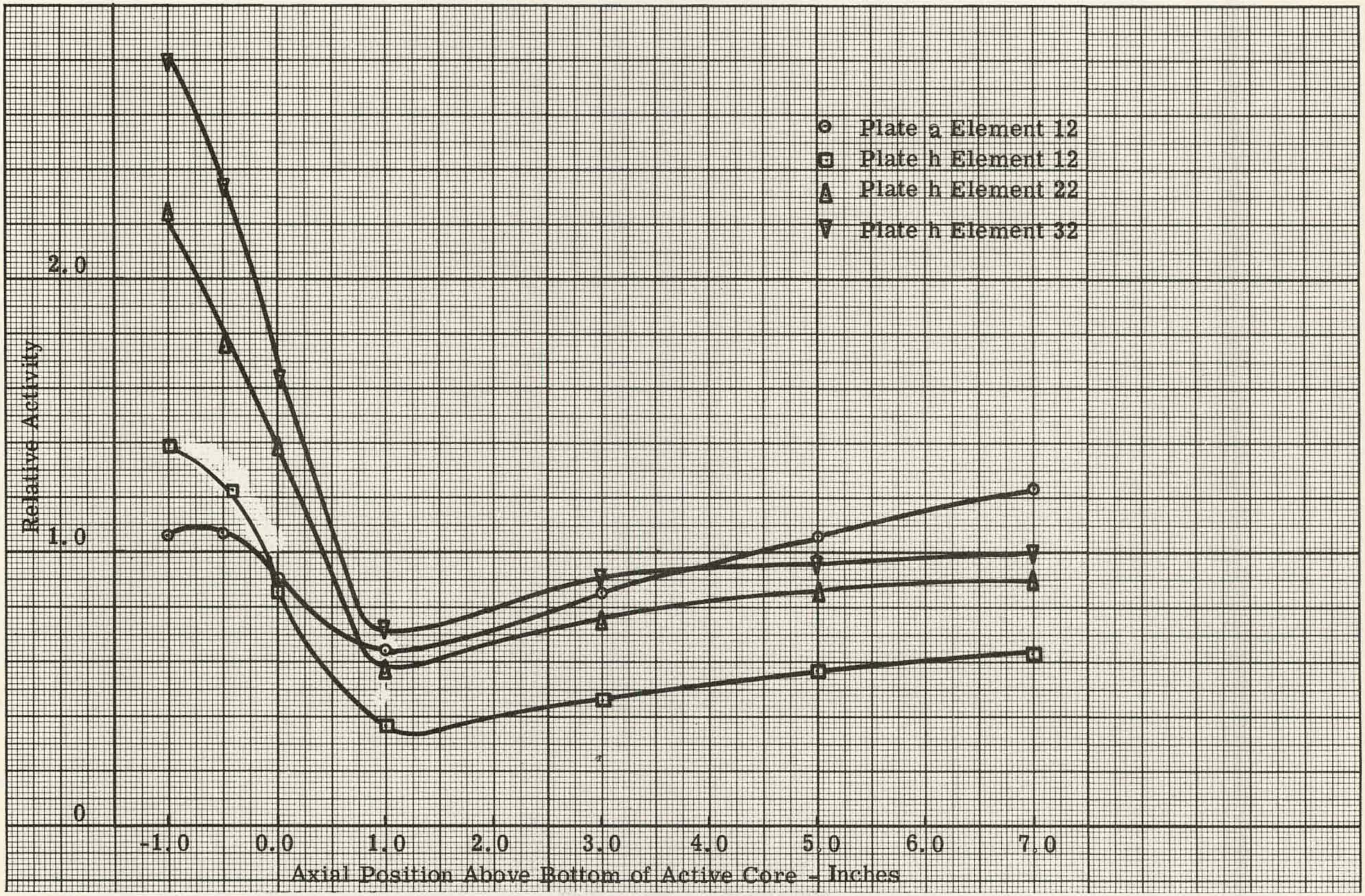

Fig. 3.12 Relative Activity vs. Axial Position - SM-1
Core II - 5.75 WRP

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Figure 3.13 shows radial flux traverses across plate a of element 41, which lies in an east-west radial plane. The three radial curves presented show effects of the bottom and side reflectors. The effect of the side reflector is more pronounced at the 3.0 in. axial plane, as is to be expected. Figure 3.14 shows a similar radial plot across plate h of element 21. The shapes of the curves presented are in agreement with those of Fig. 3.13.

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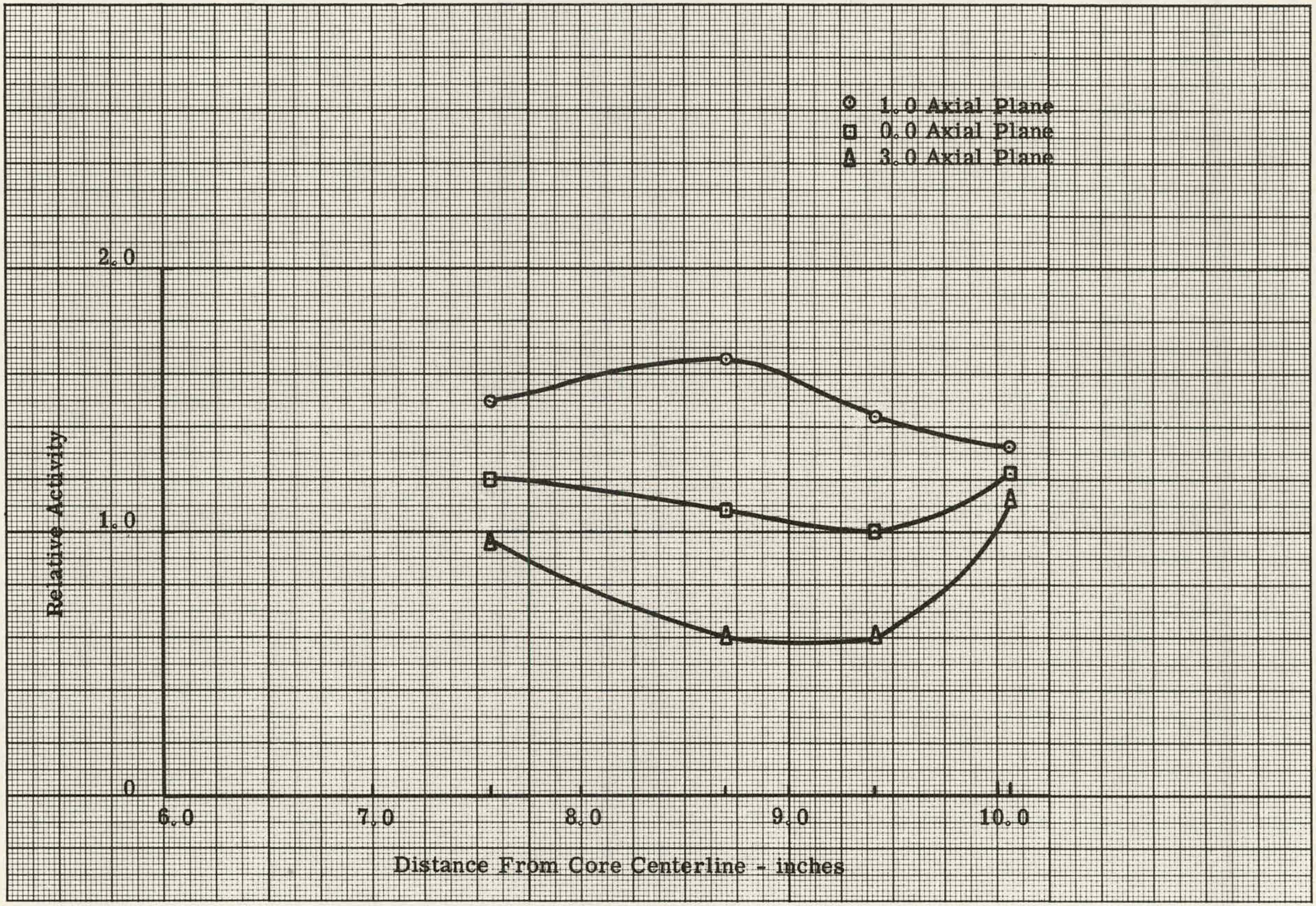

Fig. 3.13 Relative Activity vs. Radial Position in Element Position 41 - SM-1 Core II - Plate a

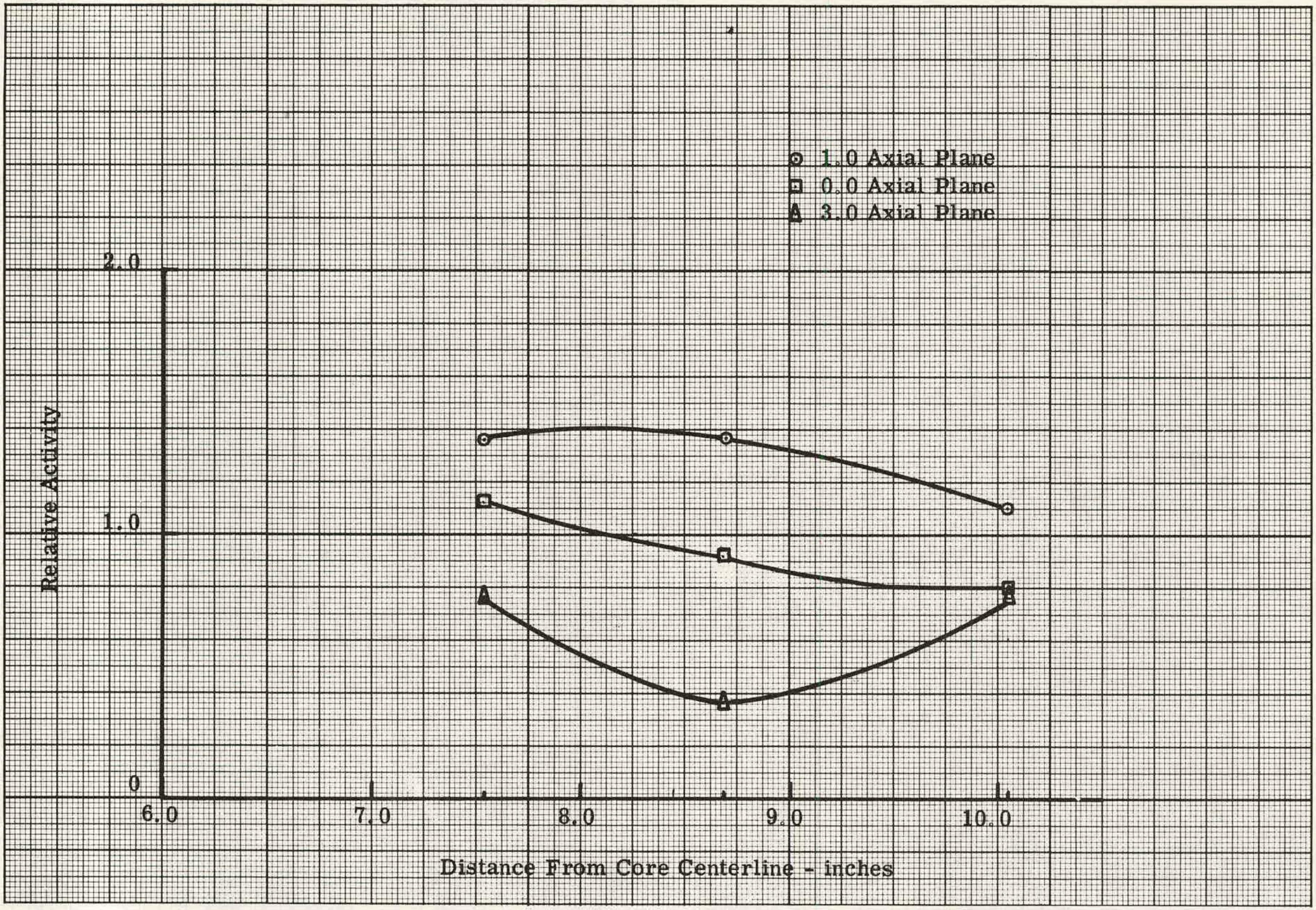

Fig. 3.14 Relative Activity vs. Radial Position in Element Position 21 - SM-1 Core II - Plate h

4.0 SM-1A CORE I-ZPE IV

4.1 INTRODUCTION

A reduced scope zero power experiment was performed on the SM-1A Core I to establish the adequacy and uniformity of a production type core. The tests included an element by element uniformity check of stationary fuel elements, a core assembly test, comparison of Eu_2O_3 and B_4C absorber sections, and development of initial core loading procedures for the SM-1A plant. The SM-1 Core II control rod fuel elements and absorber sections were reassigned to the SM-1A plant to meet the earlier SM-1A startup date. The test data for those components is presented in sections 2.2.3 and 2.3.2.

4.2 SM-1A CORE I ELEMENT CHECK

4.2.1 Procedure

Each SM-1A stationary fuel element was checked using the SM-2 mockup core by measuring reactivity differences on calibrated control rod E, with rod F withdrawn to 21.600 in. and rods A, B, C, D, and G withdrawn to 5.150 in.

4.2.2 SM-1A Core I Stationary Fuel Element Loading

Table 4.1 summarizes results of SM-1A Core I stationary fuel element uniformity measurements. Reactivity differences between the standard SM-1 element and those listed in Table 4.1 were attributed to variations in B-10 loadings. Four additional Core I elements not tabulated were rejected. From the estimated B-10 loading of the standard, reactivity differences, and known B-10 worth under test conditions, the B-10 loading of each SM-1A Core I element was estimated.

TABLE 4.1
SM-1A CORE I STATIONARY FUEL ELEMENT B-10 LOADING

Element Number	ΔK_E (cents)	B-10 Equivalent grams	Total B-10 Grams
12S	- 0.542	+ 0.005	0.368
34S	+ 1.90	- 0.016	0.347
2S	+ 1.66	- 0.016	0.347
21S	- 0.061	+ 0.001	0.364

TABLE 4.1 (CONT'D)

Element Number	ΔK_E (cents)	B-10 Equivalent grams	Total B-10 grams
18S	+ 4.56	- 0.039	0.324
39S	+ 5.44	- 0.047	0.316
6S	- 4.32	+ 0.037	0.400
9S	+ 2.05	- 0.018	0.345
29S	+ 1.06	- 0.009	0.354
3S	- 4.04	+ 0.035	0.398
35S	+ 2.71	- 0.023	0.340
28S	+ 0.725	- 0.006	0.357
26S	+ 2.17	- 0.019	0.344
11S	- 2.05	+ 0.018	0.381
16S	+ 2.27	- 0.019	0.344
32S	+ 4.23	- 0.036	0.327
36S	+ 2.08	- 0.018	0.345
27S	+ 0.783	- 0.007	0.356
30S	+ 0.878	- 0.008	0.355
14S	+ 4.20	- 0.038	0.327
8S	- 4.26	+ 0.038	0.401
24S	- 0.362	+ 0.003	0.366
13S	+ 5.29	- 0.049	0.314
1S	- 6.16	+ 0.053	0.416
15S	+ 6.24	- 0.053	0.310
23S	- 0.362	+ 0.003	0.366
17S	+ 1.39	- 0.012	0.351
46S	+ 6.73	- 0.058	0.305
20S	+ 0.181	- 0.002	0.361
38S	+ 7.81	- 0.067	0.296
43S	+ 5.49	- 0.047	0.316
33S	+ 5.83	- 0.050	0.313
47S	+ 0.181	- 0.002	0.361
40S	+ 0.544	- 0.005	0.358
31S	+ 2.18	- 0.019	0.344
25S	+ 0.211	- 0.002	0.361
10S	- 1.93	+ 0.017	0.380
22S	- 1.69	+ 0.015	0.378

Total B-10 in these 38 SM-1A Core I stationary fuel elements is 13.336 gm.

4.2.3 SM-1A Core I Reject Fuel Elements

Reactivity values far below those normally encountered and attributable to variation in boron losses were measured in four SM-1A Core I stationary fuel elements. As it is not possible to differentiate between excess of burnable poison and deficit of fuel by a single reactivity measurement, it was assumed that an error of considerable magnitude in fuel or poison loading had been made in each element. Each element underwent a series of semi-quantitative tests to establish approximate deviation from normal B-10 or U-235 loading. Significant deviation in fuel plate composition was established for each by an orientation test. Utilizing the standard sample technique, each element was (1) inserted into the reactor to obtain reactivity difference, (2) removed and rotated 180° about its vertical axis, and (3) reinserted into the reactor and a second reactivity difference obtained. Verifying tests for each of the orientations were performed, giving a total of four tests for each suspect element. Similar tests on acceptable SM-1A stationary elements showed no change in measured reactivity values with fuel element orientation. Since neither exact location of non-uniformities nor exact material coefficient at the respective locations are known, it is not possible to establish the precise nature and degree of the non-uniformities; however, average material worths measured in test position were utilized to establish an approximate range of B-10 or U-235 loadings that would account for the measured reactivity differences. Table 4.2 gives element numbers, measured reactivity differences compared to the standard element (ΔK_F), and the amount of B-10 or U-235 required for the total measured reactivity change. Inspection of Table 4.2 indicates that the non-uniformities were probably due to the loss of U-235 from one or more of the fuel plates in each of the questionable elements, as the amount of B-10 required to account for the measured reactivity change in one case (element 48-S) is about twice that normally found in an element. Subsequent information from the fuel manufacturer indicated that each of the elements contained fuel plates loaded with depleted uranium.

4.3 SM-1A CORE I ASSEMBLY TEST

4.3.1 Introduction

The full core assembly test, employing 38 stationary fuel elements, 7 control rod fuel elements and 7 B_4C control rod absorber sections was approached by means of the inverse multiplication method. As the core was loaded five rod bank critical positionsand five rod bank calibration measurements were obtained. During these tests, each fuel element was identified by a specific core lattice position to expedite on-site initial core loading and insure initial loading safety.

TABLE 4.2
SM-1A CORE I REJECT FUEL ELEMENT MEASUREMENTS

Reactivity Check and Estimated Difference in Poison or Fuel Loading Between an SM-1 Reference Element and Four SM-1A Stationary Fuel Elements. (Assumes Total Reactivity Difference is Due to Differences in either B-10 or U-235 Loading.)

Test Date, 1960	Element Number	Orientation	ΔK_E (Cents)	B^{10}* Equivalent	U-235** Equivalent
4/26	48-S	1	- 76.4	+ 0.652 gm	- 265 gm
4/22		1	- 76.4	+ 0.652	- 265
4/27		2	- 89.6	+ 0.766	- 311
4/22		2	- 89.1	+ 0.762	- 309
4/21	44-S	1	- 19.2	+ 0.164	- 66.7
4/27		1	- 19.6	+ 0.166	- 68.1
4/27		2	- 6.25	+ 0.0534	- 21.7
4/22		2	- 6.10	+ 0.0521	- 21.2
4/21	45-S	1	- 15.8	+ 0.135	- 54.9
4/28		1	- 15.5	+ 0.132	- 53.8
4/22		2	- 5.56	+ 0.0476	- 19.3
4/28		2	- 5.56	+ 0.0476	- 19.3
4/18	37-S	1	- 11.4	+ 0.0975	- 39.6
4/27		1	- 11.9	+ 0.101	- 41.3
4/22		2	- 6.54	+ 0.0558	- 22.7
4/27		2	- 6.90	+ 0.0590	- 24.0

* B-10 worth is 117 cents per gm based upon substitution of known amount of boron added to an SM-1 mockup element composed of SM-2 flexible critical fuel plates.

** U-235 worth is 0.288 cents per gm based on substitution of a known amount of U-235 into an SM-1 mockup element composed on SM-2 flexible critical fuel plates.

4.3.2 Initial Core Loading

The inverse multiplication curve for the initial core loading, presented in Fig. 4.1, extrapolates to critical mass of approximately 8 kg U-235. The reactor was critical with the five rod bank at 19.88 in. and 7.96 kg U-235, which compares favorably with ZPE-2 results of 8.08 kg U-235 reported in APAE No. 8.[6] This slight difference in critical mass is probably due to differences in core composition and geometry.

4.3.3 Core Assembly Tests

Table 4.3 lists five rod bank critical positions for various loading steps using SM-2 boron absorber sections.

TABLE 4.3
SM-1A CORE I FIVE ROD BANK CRITICAL POSITIONS VS. MASS OF U-235

Step	Loading #	Mass U-235 (kg)	5 Rod Bank Position (In.)	No. of Elements Loaded: Stationary	No. of Elements Loaded: Control Rod
1	1	7.96	19.88	10	7
2	1 + 2	8.99	15.44	12	7
3	1 + 2 + 3	10.02	12.71	14	7
4	1 + 2 + 3 + 4	12.08	10.59	18	7
5	1-5	15.17	8.34	24	7
6	1-6	16.20	7.77	26	7
7	1-7	18.26	6.74	30	7
8	1-8	20.32	5.85	34	7
9	1-9	22.38	4.09	38	7 (fully loaded)

Loading numbers of Fig. 4.2 indicate fueled lattice positions for the steps listed in Table 4.3. The 17 elements enclosed by the heavy line in Fig. 4.2 composed the minimum critical mass.

Figure 4.3 is a comparison of five rod bank critical position versus fuel loadings for the four SM-1 type cores tested to date. These curves differ appreciably; however the shapes of the curves are essentially the same and

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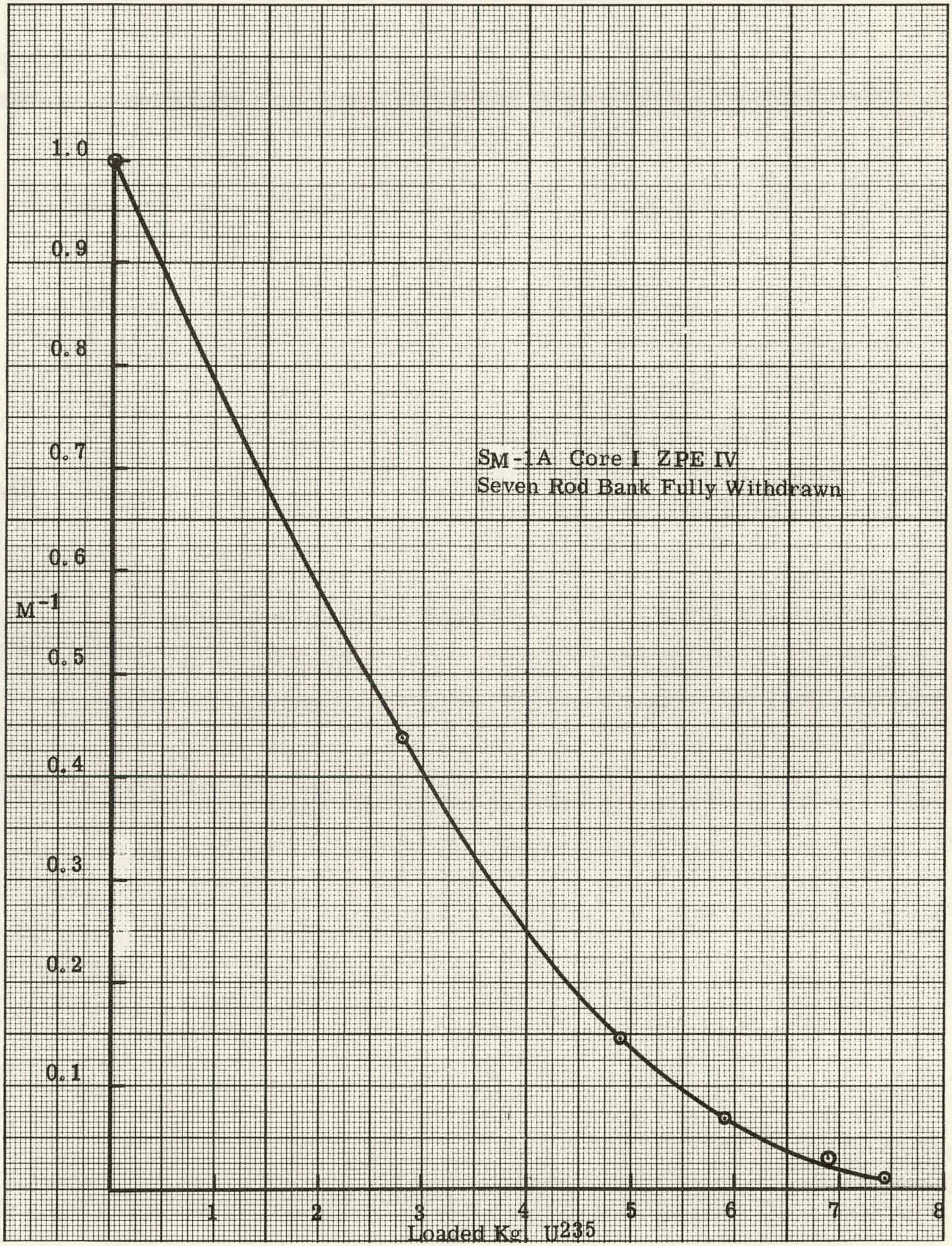

Fig. 4.1 Inverse Multiplication as a Function of U-235 Loading

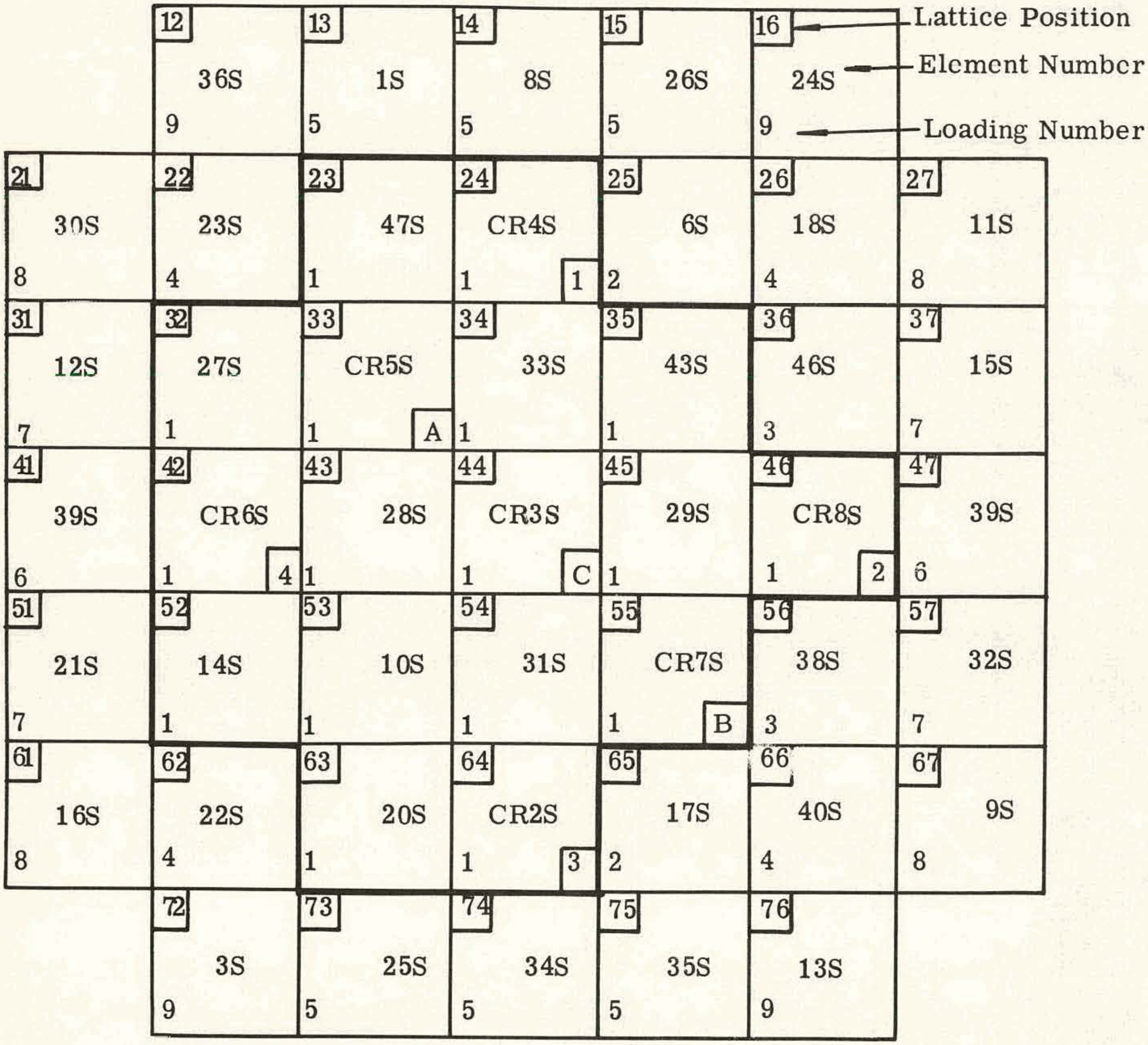

Fig. 4.2 SM-1A Core I Initial Criticality Loading

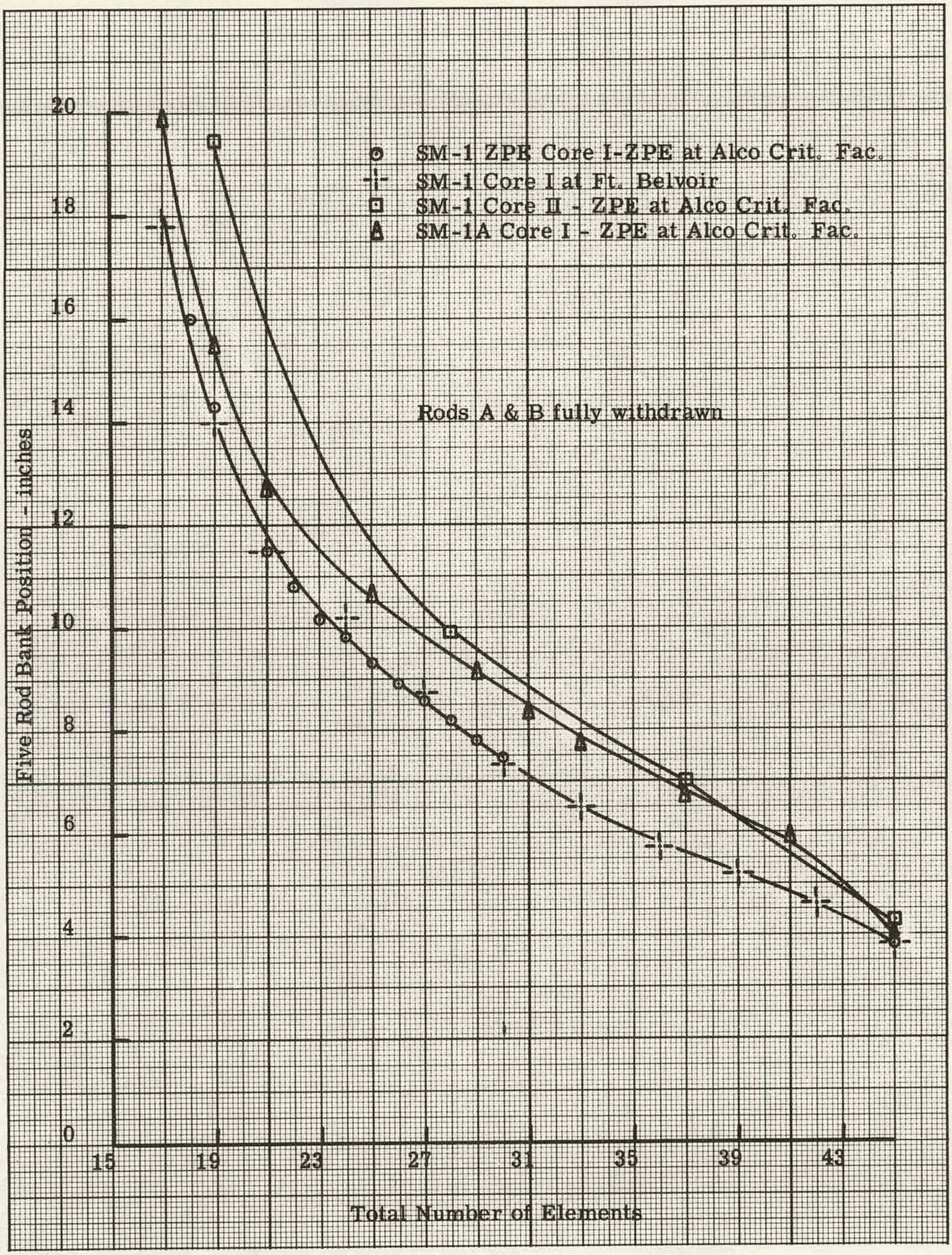

Fig. 4.3 Critical Five Rod Bank Position versus Total Number of Elements Loaded for SM-1 Type Cores

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agreement improves as the cores approach fully loaded conditions. Agreement in minimum critical mass is excellent, as shown below.

Type Core		Min. Crit. Mass	Loading
SM-1	Core I [7]	8.07 Kg	17 elements
SM-1 ZPE	Core I (ZPE-1)[6]	8.07 Kg	17 elements
SM-1	Core II (ZPE III)	not determined	
SM-1A	Core I (ZPE IV)	7.96 Kg	17 elements

Several factors contribute to the differences shown in Fig. 4.3. For loadings less than about 35 elements, five rod bank position of SM-1 Core II is considerably higher than the corresponding position of SM-1A Core I. An inspection of loading charts, Fig. 2.1 through 2.4 for SM-1 Core II and Fig. 4.2 for SM-1A Core I, shows that SM-1 Core II loadings were more asymmetrical; hence, surface to volume ratio is greater and five rod bank position more withdrawn.

If initial core loading configurations had been the same for all four cores tested, the difference shown in Fig. 4.3 would be less. However, no attempt was made to duplicate the geometry of SM-1 Core I loading steps during ZPE III and IV, as these were for development of initial core loading procedures for use at the site.

Other factors contributing to the differences shown in Fig. 4.3 are:

1. Flux suppressors: SM-1 Core II and SM-1A Core I had integral flux suppressors at the top of the control rod fuel elements with a consequent decrease in total fuel loading of 0.1 kg U-235 for the fully loaded core.

2. Boron: The B-10 loading in the SM-1 Core II is slightly heavier than that of the SM-1 Core I and the SM-1A Core I.

3. Meat boundaries: Uncertainties due to fadeout at fuel and suppressor boundaries introduce some uncertainty in actual rod withdrawal.

4. Fuel plate orientation: All outer elements of the SM-1A Core I were so oriented that their fuel plates were perpendicular to the core reflector interface on all four sides.

Differences in five rod bank position for the fully loaded SM-1 Core II and the SM-1 ZPE Core I are discussed in Section 2.6. Possible sources of error given there are generally applicable to the four different reactor cores.

Table 4.4, a compilation of comparative data for the four SM-1 series reactor cores, gives several important nuclear design differences. The B-10 loadings tabulated in Table 4.4 were obtained by different methods for SM-1 Core I and SM-1 ZPE Core I (by destructive chemical analysis of reject fuel plates) and for the SM-1 Core II and the SM-1A Core I (by reactivity comparisons with a standard element). Critical bank position for the first two cores was obtained by utilizing the SM-1 core support structure while the second two cores were tested in the SM-2 flexible critical experiment core support structure. The absolute accuracy of the data in Table 4.4 cannot be assured. It is noted that the SM-1 Core II test was performed with seven SM-2 mockup B_4C absorbers (made to SM-1 Core I specifications) and the control rod fuel elements of SM-1A Core I, because SM-1 Core II Eu_2O_3 absorber sections and control rod fuel elements had not been received for testing.

4.3.4 Comparison of Eu_2O_3 and B_4C Absorber Sections

The five rod bank critical position for the SM-1A was 3.642 in. withdrawn with seven Eu_2O_3 absorber sections and 4.092 in. withdrawn with seven B_4C absorber sections (SM-2 boron absorbers made to SM-1 Core I specifications), as shown in Table 4.4. Using the five rod bank calibration curve, Fig. 4.4, this difference in bank positions is equivalent to about 60 cents.

4.4 FIVE ROD BANK CALIBRATION

During initial core assembly tests, the five rod bank was calibrated to aid in the reactivity estimations of the various loading configurations. Fig. 4.4 is the curve generated as a function of fuel loading, and hence, core size. Specific points on the curve are numbered and correspond to calibrations performed during the various loading steps listed in Table 4.3. Each point is most valid for the core configuration in which it was measured. SM-1 Core II calibration points are plotted for comparison on the graph. Several calibration points were obtained in the fully loaded SM-1A core by varying the poison using boron steel strips inserted uniformly throughout the core. B_4C absorber sections were used in the control rods during this test.

Figure 4.5 is a comparison of the SM-1A Core I and SM-1 Core II composite calibration curve with the SM-1 ZPE Core I and SM-1 mockup Core (4) composite calibration curve. The two curves have a similar shape, slightly displaced in the lower bank positions.

This data indicates that the displacement is due to the presence of integral flux suppressors in the control rod fuel elements of the SM-1A Core I and the SM-1 Core II. For comparison of future SM-1 series reactor cores utilizing integral flux suppressors with the SM-1 Core I, it may prove convenient to define the control rod position of deepest insertion as representing the nominal alignment of the bottom of the active core with the top limit of the U-235 distribution in the control rod fuel element, rather than the top limit of the flux suppressor distribution.

TABLE 4.4
COMPOSITE DATA FOR SM-1 TYPE REACTOR CORE

	SM-1 Core I †	SM-1 ZPE Core I †	SM-1 Core II	SM-1A Core I
Number of stationary fuel elements	38	38	38	38
Number of control rod fuel elements	7	7	7***	7
Total No. of fuel elements	45	45	45	45
Absorber Sections (Number and type)	7 B_4C	7 B_4C	7 Eu_2O_3 ***	7 Eu_2O_3
Total Mass U-235 fully loaded core (kg)	22.48	22.48	22.38	22.38
Estimated B-10 Content of Stationary fuel elements (gm)	13.70 *	13.70*	13.96**	13.34**
Estimated B-10 Content of Control Rod fuel elements (gm)	2.05*	2.05*	------	1.97*
Estimated Total B-10 content fully loaded core (gm)	15.75	15.75	------	15.31
Flux suppressors (at top of control rod fuel elements)	External Combs	None	Integral	Integral
Five rod cold clean critical bank position (inches)	3.83 ††	3.83 ††	4.15 with 7 B_4C absorbers	3.64 4.09 with 7 B_4C absorbers
Type reflector	0.050 SS Skirt, Water	0.050" SS Skirt, Water	Water	Water †††
Stationary fuel element fabricator	ORNL	ORNL	SYLCOR	SYLCOR
Control rod fuel element fabricator	ORNL	ORNL	ORNL	ORNL
Absorber Section fabricator	ORNL	ORNL	ORNL	ORNL

† The SM-1 core I is the actual core in use at Ft. Belvoir, Va. The SM-1 ZPE Core I was used in the ZPE I & II.

* Values based on design specifications minus losses as determined by chemical analysis performed on Reject Fuel-Plates.

** Values based on reactivity differences obtained by intercomparison with an SM-1 standard element. (Ref. Paragraph 2.2)

*** Control rod fuel elements and absorbers not available.

†† 0.13 inches dial correction added to original data reported in APAE No. 8 and 18.

††† Outer fuel plates normal to water reflector.

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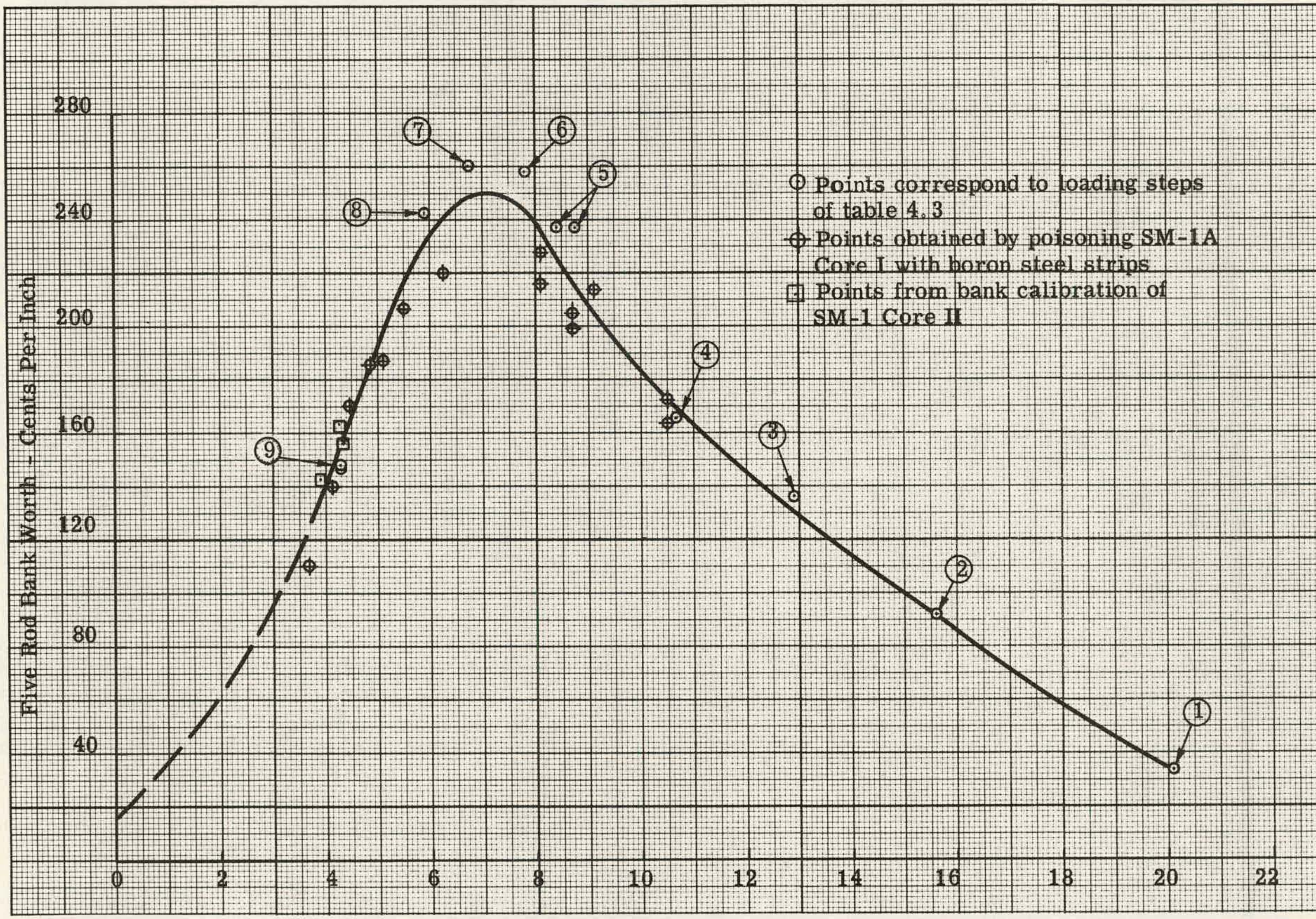

Fig. 4.4 SM-1A Five Rod Bank Calibration

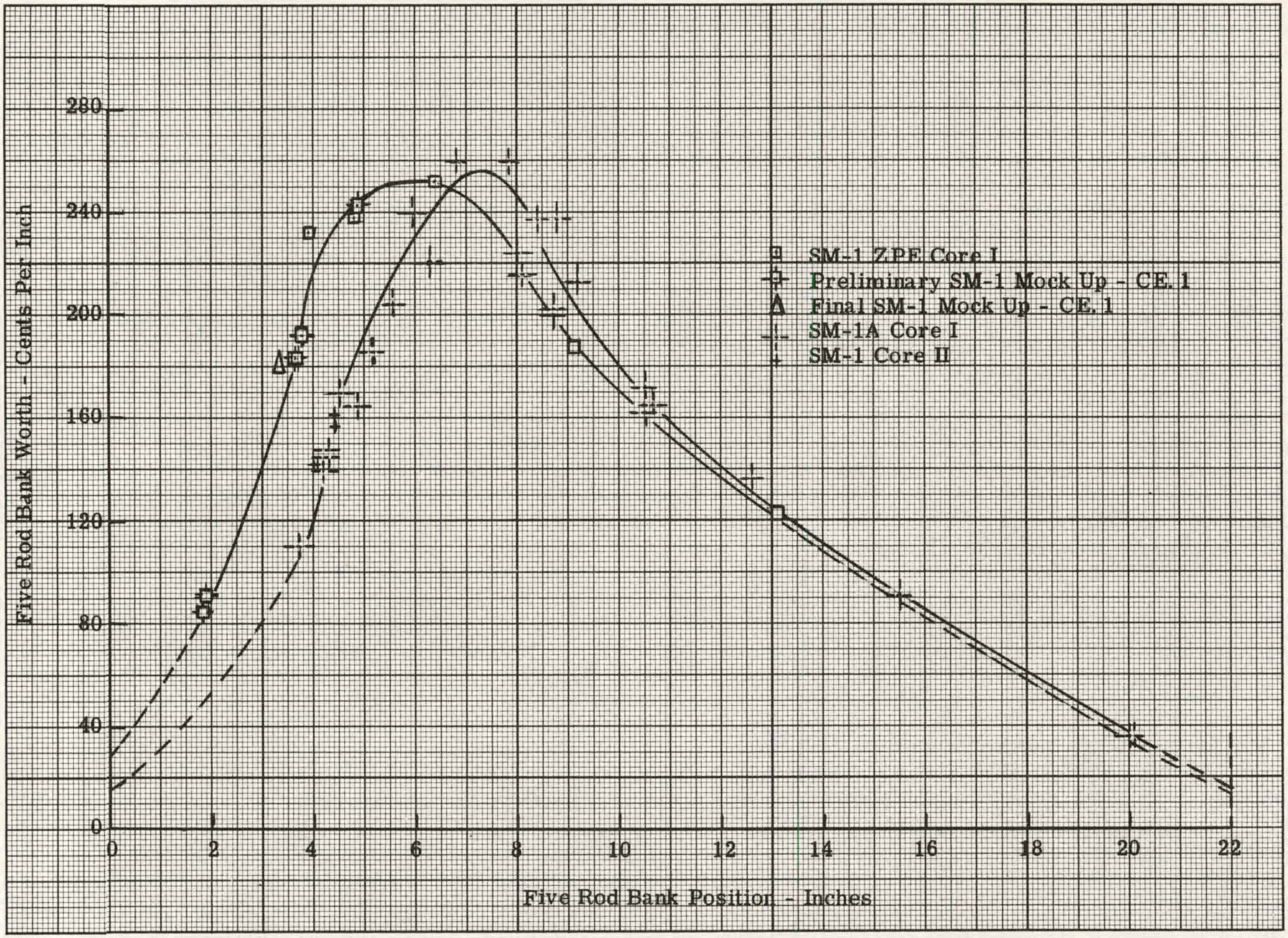

Fig. 4.5 Comparison of SM-1 Series Reactor Calibration Curves

4.5 INITIAL ON SITE LOADING FOR THE SM-1A CORE I

Initial core loading procedure for use at the SM-1A site was developed from data generated by initial loading at the critical facility. The procedure requires exact reconstruction of the core as assembled at the Critical Facility, and permits rapid, safe initial core loading without the necessity of duplicating the inverse multiplication curve. Table 4.5 presents the proposed loading procedure, in which each element is assigned a specific core lattice position and loading sequence. Under this procedure element numbers and loading sequence listed for loading number 1 would be completed and a startup channel count rate taken with all rods fully inserted. Rods A and B would be fully withdrawn and a second startup channel count rate taken. When a minimum count rate of 2 cps is obtained in the startup channel (with rods A and B withdrawn), the five rod bank will be withdrawn to attain criticality. Listed in Table 4.5 are the five rod bank critical positions, bank worth, and approximate shutdown margin with all rods fully inserted. The critical bank positions and bank worth were obtained from ZPE data, while the approximate shut-down margins were obtained by taking integral five rod bank worth between zero and the critical position and adding to that the essentially constant worth of the two cocked rods A & B. Estimated worth of cocked control rods A & B were obtained by taking the difference between the five and seven rod bank worth curves previously reported.(8)

A mockup test in which the core-startup channel orientation was quite similar to the actual SM-1A configuration indicated that neutrons will be detected in the startup channel with control rods A & B fully withdrawn after completion of loading number 2. Figure 4.7 illustrates SM-1A core orientation, element numbers, loading sequence, and lattice positions.

TABLE 4.5

SM-1A CORE I STARTUP LOADING DATA

Loading Number	Element Number	Core Position	Loading Sequence	Approximate Five Rod Bank Critical Position-inches. Rods A & B Fully Withdrawn	Approximate Shutdown Margin-dollars. All Rods Fully Inserted	Approximate Five Rod Bank Worth-cents/inch
	CR6S	42	1			
	EuSS10					
	CR5S	33	2			
	EuSS11					
	CR4S	24	3			
	EuSS2					
	CR3S	44	4			
	EuSS7					
	CR2S	64	5			
	EuSS9					
	CR7S	55	6			
	EuSS12					
	CR8S	46	7			
	EuSS13					
1	31S	54	8			
	33S	34	9			
	28S	43	10			
	29S	45	11			
	10S	53	12			
	43S	35	13			
	46S	36	14			
	38S	56	15			
	47S	23	16			
	6S	25	17			
	14S	52	18			
	27S	32	19			
	17S	65	20			
	20S	63	21			
	23S	22	22			
	18S	26	23			
	22S	62	24			
	40S	66	25			
	25S	73	26			

TABLE 4.5 (CONT'D)

Loading Number	Element Number	Core Position	Loading Sequence	Approximate Five Rod Bank Critical Position-inches. Rods A & B Fully Withdrawn	Approximate Shutdown Margin-dollars, All Rods Fully Inserted	Approximate Five Rod Bank Worth-cents/inch
	35S	75	27			
	1S	13	28			
	26S	15	29	9.0 ± .5	21	208
2	8S	14	30			
	34S	74	31			
	39S	41	32			
	2S	47	33	7.6 ± .4	17	247
3	12S	31	34			
	15S	37	35			
	21S	51	36			
	32S	57	37	6.6 ± .4	15	246
4	30S	21	38			
	11S	27	39			
	16S	61	40			
	9S	67	41	5.7 ± .3	13	225
5	36S	12	42			
	24S	16	43			
	3S	72	44			
	13S	76	45	4.3 ± .2	10	154

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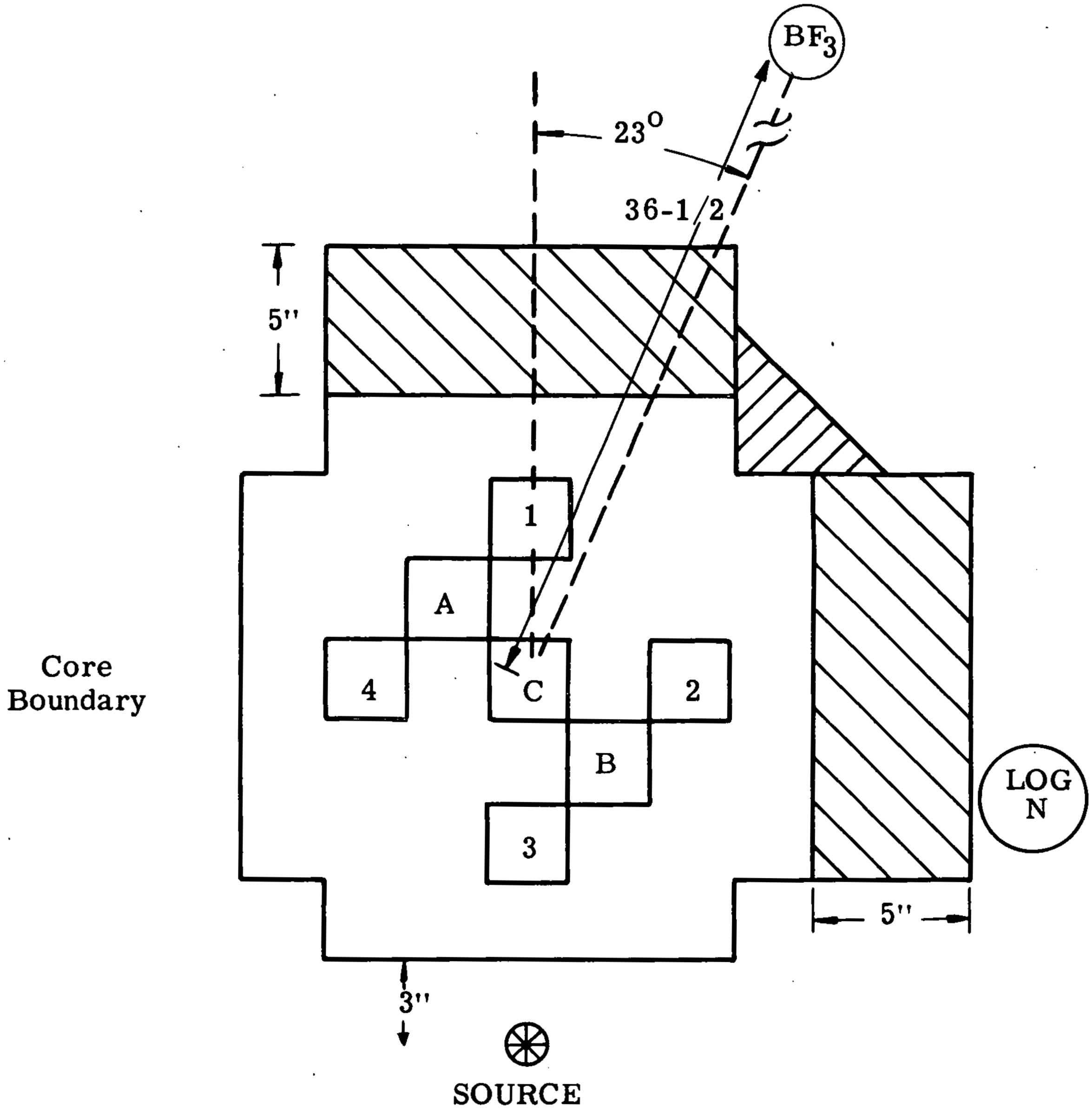
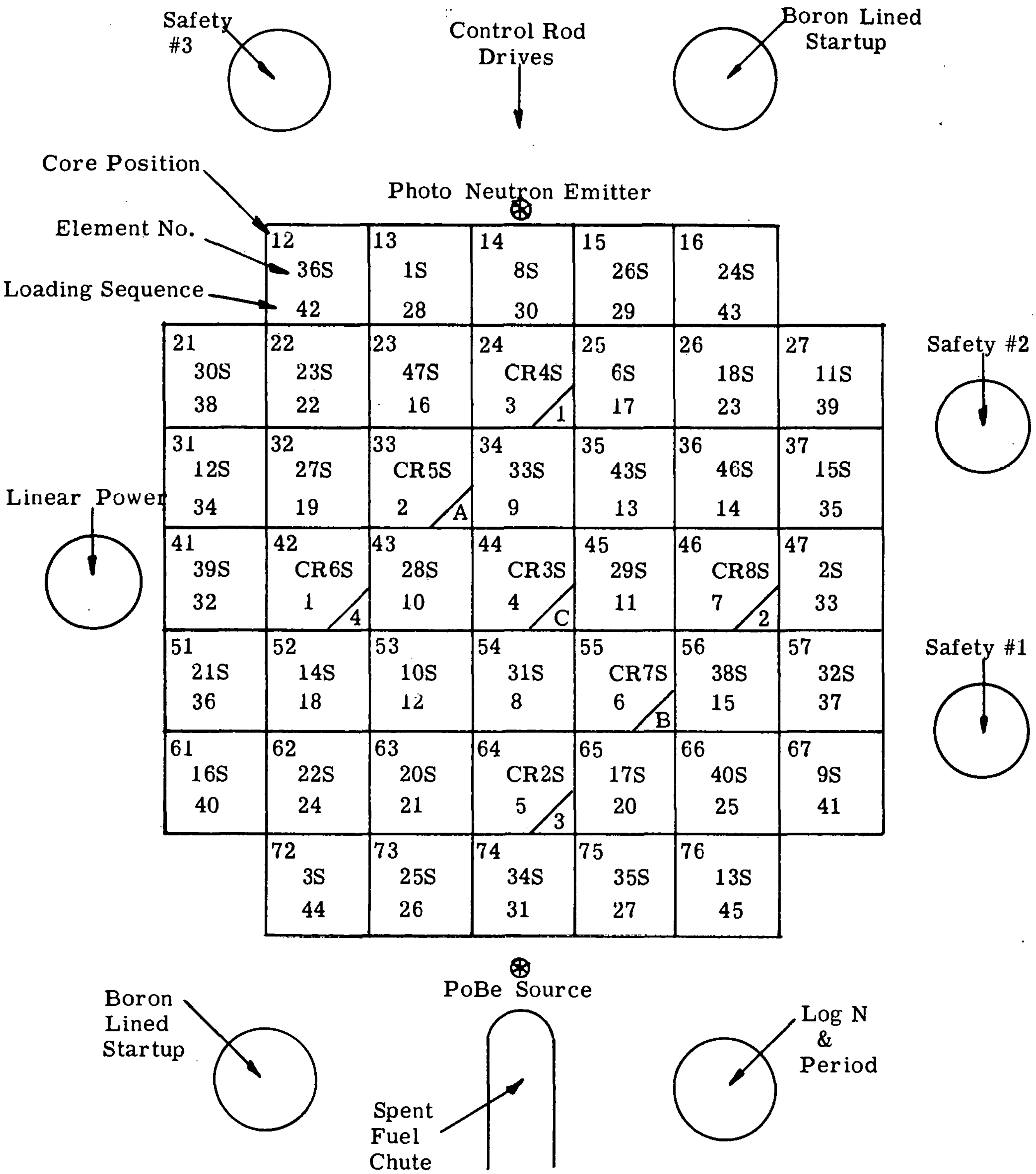


Fig. 4.6 Core Configuration for Startup Count Rates



Plates run parallel to the source and drives .
All outside plates are perpendicular to reflector.

Fig. 4.7 SM-1A Loading Chart

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APPENDIX A

SM-1 CORE II SUPPLEMENTARY FLUX MEASUREMENTS

Supplementary flux measurements for Task XV SM-1 Core II, were suggested. However, as Core II elements had already been shipped from the critical facility, measurements were made using SM-1A Core I fuel elements. The core configuration was exactly the same as for the SM-1 Core II. Control rods A and B were fully withdrawn and control rods 1, C, and 4 were at 4.162 in. The reactor was brought critical with control rods 2 and 3 withdrawn 3.582 in.

All foils were activated simultaneously. The reference foil was positioned as in previous measurements; fuel element position 53, plate r, 2.938 in. WRP, and the 2.875 in. axial plane.

The results are tabulated in Table A-1, using previously defined nomenclature. Figure A-1 illustrates the locations and relative activities of fission foils.

TABLE A-1 - RELATIVE ACTIVITIES* OF FISSION FOILS ALL MEASUREMENTS TAKEN AT 2.28" AXIAL PLANE STATIONARY ELEMENTS

	El. Pos. #14		El. Pos. #15		El. Pos. #16	El. Pos. #21		El. Pos. #22	
Plate Letter	0.125 ERP	1.125 ERP	1.813 ERP	4.063 ERP	4.750 ERP	9.938 WRP	7.688 WRP	7.000 WRP	4.750 WRP
"a" North Side	2.05**	1.19	1.06	1.22	1.06	1.02	1.12	0.89	0.87
"r" South Side		0.99	0.87		0.84	0.75	0.80		1.12

	El. Pos. #25	El. Pos. #26	El. Pos. #31		El. Pos. #32		El. Pos. #34	El. Pos. #35
Plate Letter	1.813 ERP	4.750 ERP	7.688 WRP	9.938 WRP	4.750 WRP	7.000 WRP	1.135 ERP	1.813 ERP
"a" North Side			0.86	0.73	1.03	0.84		
"r" South Side	1.08	1,09	0.91	0.82	1.28	1.00	1.37	1.22

	El. Pos. #41		El. Pos. #43		
Plate Letter	7.688 WRP	9.938 WRP	1.813 WRP	4.063 WRP	2.813 WRP
"a" North Side	0.92	0.89	1.30	1.29	
"r" South Side	0.93	0.87	1.18	1.13	
"h" South Side					0.97

CONTROL RODS

	ROD 1				ROD C			
Plate Letter	1.125 WRP	CL	0.125 ERP	1.125 ERP	1.125 WRP	CL	0.125 ERP	1.125 ERP
"a" North Side	1.07	0.82		1.10	1.45	1.16		1.47
"p" South Side	1.29	1.00		1.24	1.44	1.07		1.33
"g" South Side			0.83				0.98	

	ROD 4				ROD A			
Plate Letter	4.750 WRP	5.875 WRP	5.750 WRP	7.000 WRP	1.813 WRP	2.813 WRP	2.938 WRP	4.036 WRP
"a" North Side	1.39	0.76		1.10	1.35		1.04	1.29
"p" South Side	1.24	0.86		1.03	1.48		1.14	1.35
"g" South Side			0.86			0.97		

* Activities normalized to reference foil in fuel element position 53, plate "r", 2.938" WRP, 2.875" axial plane

** Foil placed on outside of 1/4" of plastic

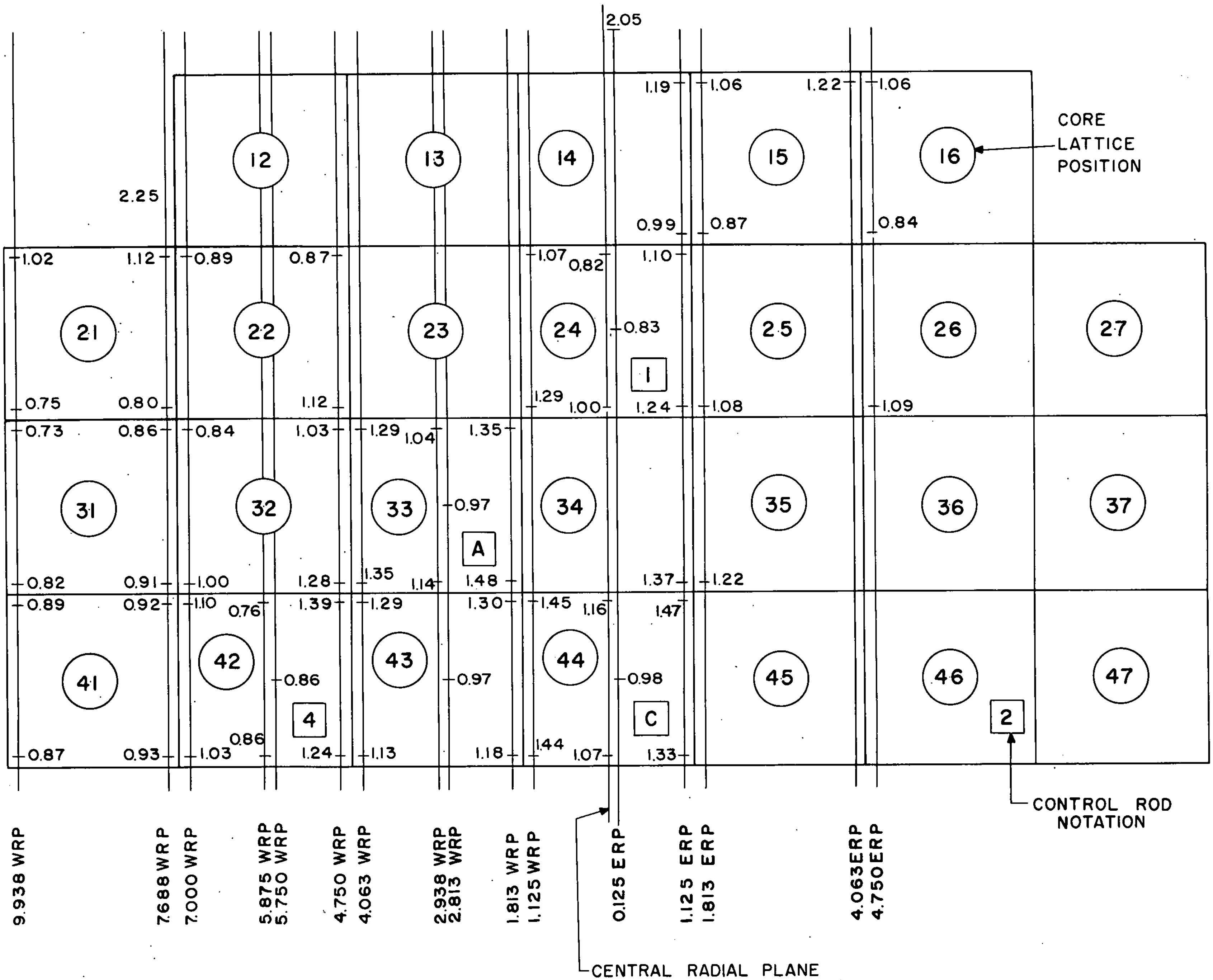

Fig. A.1 SM-1 Core II - Location and Relative Activities of Fission Foils