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startup and initial testing of SM-1 core II with special components

Contract No. AT[30-1]-2639
with U. S. Atomic Energy Commission
New York Operations Office

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ALCO PRODUCTS, INC.
NUCLEAR POWER ENGINEERING DEPARTMENT

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APAE Memo-305
AEC Research and Development Report
UC-81, Reactors-Power
(Special Distribution)

STARTUP AND INITIAL TESTING OF SM-1 CORE II WITH SPECIAL COMPONENTS

By:
F. G. Moote
E. W. Schrader

Approved by:
M. H. Dixon, Project Engineer

Issued: February 28, 1962

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with U. S. Atomic Energy Commission
New York Operations Office

ALCO PRODUCTS, INC.
Nuclear Power Engineering Department
Post Office Box 414
Schenectady 1, N. Y.

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1.0 SUMMARY

The report gives the loading operation for SM-1 Core II, and results of startup physics measurements (Test A-300 Series) and fission product iodine monitoring in the primary coolant.

The SM-1 Core II initial loading progressed satisfactorily, fulfilling the predictions of the zero power experiment performed at the Alco Criticality Facility. The initial cold clean five rod bank position was 6.53 in.; the initial hot, no xenon, five rod bank position was 9.62 in.; the initial hot, equilibrium xenon, five rod bank position was 11.41 in.; and the initial hot, peak xenon, five rod bank position was 12.14 in. Rods A and B were at 19.00 in. in all four measurements.

Stuck rod measurements indicated that an adequate shutdown margin was available with 20% of the rods fully withdrawn.

All rod calibrations indicated a distinct shift and broadening of the peaks when compared with similar Core I calibrations. More detailed investigation of the rod calibrations will be required to clarify this effect.

The temperature coefficient for Core II is -3.5 cents/^{o}F at 440^{o}F.

Equilibrium xenon was worth approximately -$3.00 while peak xenon was worth -$4.43, both relative to the hot, no xenon core condition.

During the period June 2, 1961 through September 30, 1961 the reactor operated at total of 935.68^{o}F days which is equivalent to 1.34 MWYR of energy release and represents an average load factor of 44% typical of training periods.

The estimated reactivity in the core at startup is $10.00. A core life of 12.2 MWYR is predicted for the original configuration of Core II.

The results of gross fission product iodine monitoring showed that those levels were about one-third to one-half of those found at the end of Core I Operation.

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2.0 INTRODUCTION

Core II was loaded into the SM-1 during the period May 31 to June 2, 1961. Initial criticality of Core II with special components [1][2] was achieved on June 2, 1961. A core testing period followed and was completed on June 26, 1961. During this testing period, physics measurements (TP-A300 series) were performed which included startup channel calibrations, five rod bank positions, stuck rod measurements, rod calibrations, temperature coefficient, and transient xenon measurements, for the purpose of determining the operating characteristics of the SM-1 Core II with special components. Comparison of Core II data with Core I characteristics are presented where differences are evident. Results of such comparisons will help define the magnitudes of various parameters which are due to the special elements in Core II. Abstracts of test procedures performed are found in reference (3).

SM-1 Core II Operation, June to September 1961

During the period from June 26 to September 30, 1961, the plant was operated on a routine training schedule which includes daily cycles of startups, shutdowns, load changes and full power runs of 8 hr or more to maintain water purity. A load factor of approximately 50 percent was typical during this training period except for those times when lengthy shutdowns were required for maintenance work. As of September 30, 1961 the integrated energy output of SM-1 Core II was 935.68°F days or 1.34 MWYR. This represents an average load factor of 44% for this period. Due to the cyclic training type operation of the plant the attempt to measure the core reactivity effects resulting from SM-149 buildup was invalidated by the large and fluctuating core temperature and xenon concentration reactivity effects.

Several delays in the training cycles of durations ranging from a few hours to a day or more occurred as a result of difficulties in the operation of the startup channels. Some of the difficulties were electronic and others may be attributed to radiation effects on the BF_3 chambers, and coaxial cables. The startup channel calibrations are affected by radiation exposure so that optimum instrument operational settings may drift during reactor operations. Difficulties with the startup channel instrumentation prevented the collection of quantitative data for the evaluation of neutron source decay.

A lifting mechanism was installed on one of the BF_3 chambers in October 1961 (Test A-503), which should minimize the problem of radiation damage and permit continuous operation of that startup channel at optimum settings until adequate overlap of operation is established between it and intermediate range instrumentation. The BF_3 chamber in channel #2 was replaced during the July 1961 shutdown.

Excessive leakage of high pressure water from the control rod drive shaft seals caused the seal leakage return pumps to run continuously by August 10, 1961. From August 10 to 19, the reactor was operated at reduced power (4 MW), reduced pressure (1000 psi) and reduced temperature (430°F) in order to reduce the leakage rate. The plant was shutdown from August 20 to 25 while three seals and shafts were being replaced. An estimated 75% of the leakage was found to be from control rod C. Since replacement of the three shafts and seals, the leakage rate was reduced to original levels of 0.3 gpm with the makeup pumps running 5 - 10% of the time.

As a result of the training operations scheduled, the initial testing was reduced to meet only the minimum requirements to insure satisfactory operation of the plant. From an operating standpoint, this was satisfactorily demonstrated. However, an ORNL hot cell examination of element S 79 which was removed from Core I in June 1960, revealed transgranular cracking of the cladding of that element. Therefore, concern was expressed about the continued irradiation of Core I elements S 80 and S 81 then in Core II. As a result, the frequency of fission product monitoring of water samples was increased to a daily basis and radiation levels were monitored hourly at the primary make-up tank. In addition, the monitor in the primary blowdown line was repaired and put into continuous operation. No indications of fuel failures nor any abnormal fission product activity in the primary coolant were observed during this period.

Work covered in this report was performed as part of Items 2.4 and 2.8 and Task 5 of Fiscal Year 1961 Program Plan for Engineering Support and Development of Army Pressurized Water Reactor Power Plants.

3.0 SM-1 CORE II LOADING

3.1 SYSTEM DESCRIPTION

SM-1 Core II is composed of 32 regular stationary elements, two high burnup SM-1 Core I stationary elements, two SM-2 stationary elements, (previously in SM-1 Core I) and two material test elements; seven regular control rod fuel elements with five Eu_2O_3 absorber sections, (previously in Core I) one new Eu_2O_3 absorber section, and one gradiated boron absorber section.[1], [2]

The core orientation, lattice positions, and control rod array are identical to the configuration originally set for Core I.[4] The only change is the replacement of the fission counter with a BF_3 chamber. The Log N and safety chamber locations have remained the same.

The startup source for Core II is the same dual PoBe-SbBe source which replaced the original PoBe at the end of Core I life[5] (before rearrangement). The original beryllium block to act as a photoneutron source is still fixed to the core skirt.

Table 3.1.1 presents the material composition of the SM-1 Core II. Core component locations are illustrated in Fig. 3.1.1. Detail descriptions of these components are published in other reports.[1], [2], [6], [7]

3.2 CORE II LOADING OPERATION

The SM-1 Core II loading was conducted according to procedures [8] which were based upon the results of work performed at the Alco Products, Inc. Criticality Facility.[1], [6] The loading operation commenced on May 31, 1961 and was completed on June 2, 1961.

The loading of the SM-1 Core II was executed in a seven stage sequence outlined below:

1. Insertion of the two material test elements and the seven control rod assemblies (fuel elements and absorbers); Caps locked on control rod assemblies prior to subsequent fuel additions.

2. Insertion of the two high burnup SM-1 Core I and two low burnup SM-2 fuel elements.

3. Addition of six SM-1 Core II stationary fuel elements.

TABLE 3.1.1
MATERIAL COMPOSITION OF SM-1 CORE II
WITH SPECIAL COMPONENTS*

	Number of Core	Fuel Elements U-235 grams per element	Fuel Elements B-10 grams per element
SM-1 Core II Stationary Elements	32	515.16	.4163
SM-1 Core II Control Rod Fuel Elements	7	402.12	.2813
SM-2A Stationary Element	1	866.7	1.54
SM-2B Stationary Element	1	861.6	1.35
High Burnup Core I (1) Stationary Elements	2	278.0	.011
Material Test Elements	2	------	------
		Absorber Section	
SM-1 Core II Eu_2O_3 Absorbers originally in SM-1 Core I	5 (Eu_2O_3)	120	grams** Eu
SM-1 Core II Eu_2O_3 Absorber new in SM-1 Core II	1 (Eu_2O_3)	124	grams Eu
Graduated Boron Steel Absorber	1	40	grams B-10

* PM-1-M elements and Task XIV instrumented elements not available for initial loading of Core II. These will be added at a later date.

** Estimate of original Eu atoms present.

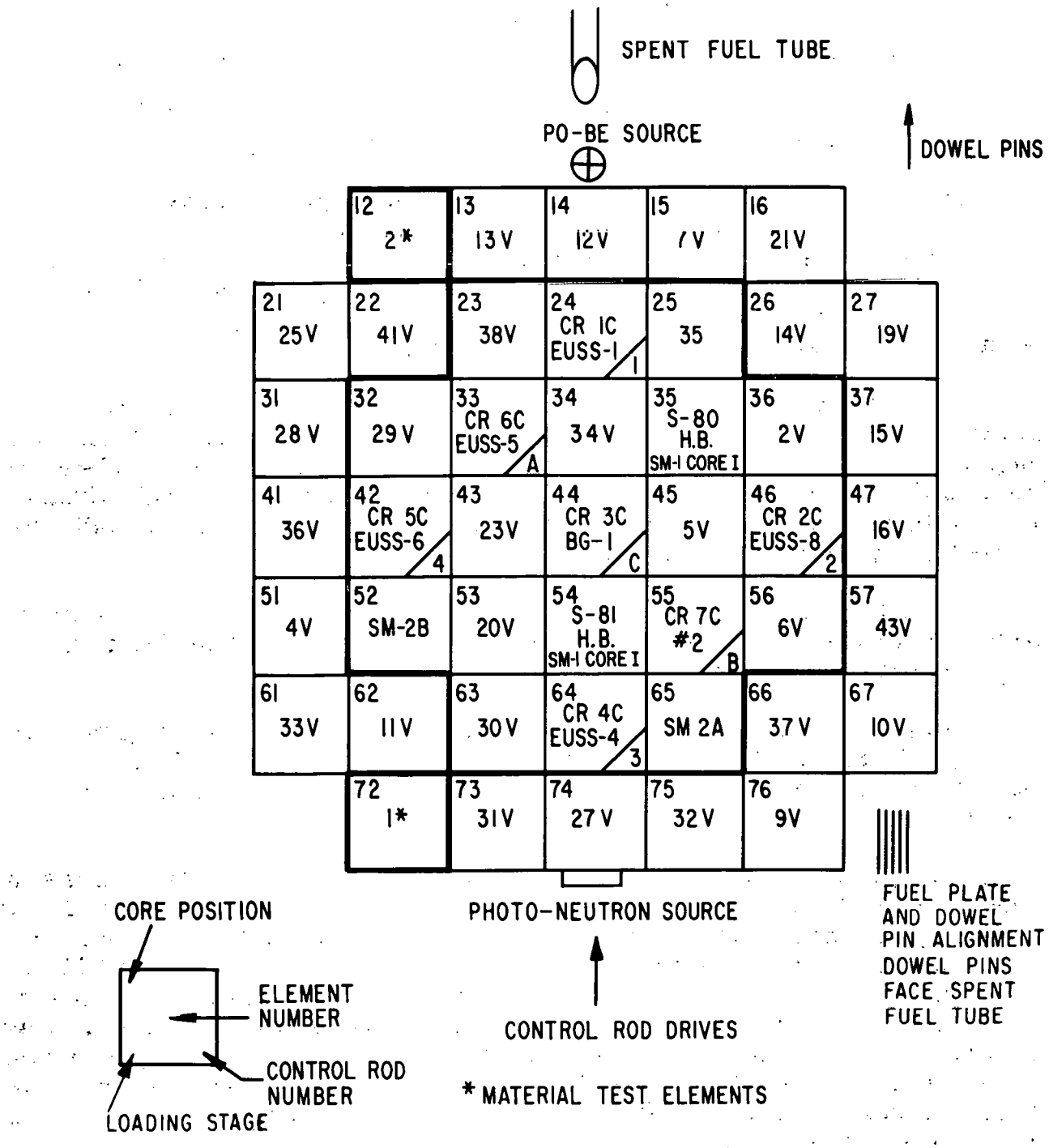

Figure 3.1.1. SM-1 Core II With Special Components

4. Insertion of four SM-1 Core II elements.

5. Insertion of seven SM-1 Core II elements.

6. Insertion of eight SM-1 Core II elements.

7. The loading was completed by the addition of seven SM-1 Core II elements.

Figure 3.1.1 shows the composition and fuel plate orientation of the fully loaded SM-1 Core II with special elements. The orientation of the control rod fuel elements was such that the numbered side faced the spent fuel tube. The stationary fuel elements were oriented so that all dowel pins pointed in the direction of the spent fuel pit. The plane of the fuel plates is parallel to the source-control rod drive axis of the core for all elements.

All fuel additions after stage 1 (loading of control rod assemblies) were made with rods A and B cocked at 8 in. withdrawn. One 5-min count rate was obtained on each BF_3 prior to initiating the core loading. At the completion of each loading step, 5-min count rates were obtained with rods A and B first at 8 in. withdrawn and then at 19 in. withdrawn. The five rod bank was fully inserted during these measurements.

Initial criticality was obtained after the fourth loading step. The heavy solid line in Fig. 3.1.1 encompasses the core configuration after the fourth loading step.

Table 3.2.1 is a compilation of the nuclear data obtained during the core loading. It includes loading sequence, five rod bank critical positions and startup channel count rates. The moderator temperature during the core loading was approximately $70^{\circ}F$.

Table 3.2.1 shows that, with the exception of the initial critical position (obtained after the fourth loading stage), the actual and estimated five rod bank critical positions agreed quite well. The actual initial five rod bank critical position of 15.82 in. was 1.68 in. lower than the estimated position of 17.50 in.,[8] resulting in an increase in core reactivity of 139 cents at this loading based on the five rod bank calibration curve obtained during the ZPE.[6] This indicated an increased worth of the actual SM-1 high burnup and SM-2 low burnup elements in Core II over that predicted by the ZPE. It is assumed that the difference is a result of either overestimating the actual element burnups or underestimating the loading of the mockup elements.

TABLE 3.2.1
TABULATION OF SM-1 CORE II LOADING DATA

Loading Stage No.		Elements & Absorbers Loaded	Core Position No.	Five Rod Bank Critical Position, Inches Rods A and B at 19.0 In.		Startup Channel Count Rates (cps) Rods A & B at			
						8.0 Inches		19.0 Inches	
				Estimated	Actual	BF_3#1	BF_3#2	BF_3#1	BF_3#2
I	#2	(Material Test Element)	12						
	#1	(Material Test Element)	72	Subcritical		0.08	0.94	-	-
		CR8C	44						
		BG-1 (Absorber)	44						
		CR6C	33						
		EUSS-5 (Absorber)	33						
		CR7C	55						
		#2 (Absorber)	55						
		CR1C	24						
		EUSS-1 (Absorber)	24						
		CR2C	46						
		EUSS-8 (Absorber)	46						
		CR4C	64						
		EUSS-4 (Absorber)	64						
		CR5C	42						
		EUSS-6 (Absorber)	42						
II		S-80 (SM-1 Core I)	35	Subcritical		0.11	0.68	0.08	0.66
		S-81 (SM-1 Core I)	54						
		SM-2A	65						
		SM-2B	52						
III		34V	34	Subcritical		0.09	0.62	0.06	0.73
		23V	43						
		5V	45						
		20V	53						
		29V	32						
		2V	36						
IV		38V	23	17.5	15.82	0.07	0.74	0.07	0.74
		35V	25						
		30V	63						
		6V	56						
V		14V	26	11.3	10.958	0.17	1.50	0.16	1.52
		25V	21						
		41V	22						
		21V	16						
		7V	15						
		12V	14						
		13V	13						
VI		19V	27	8.3	8.20	0.38	2.16	0.49	2.65
		15V	37						
		16V	47						
		43V	57						
		28V	31						
		36V	41						
		4V	51						
		33V	61						
VII		10V	67	6.6	6.53	0.34	2.40	0.67	3.18
		37V	66						
		11V	62						
		31V	73						
		27V	74						
		32V	75						
		9V	76						

Due to the uncertainties in determining the boron loading of Mylar tapes used in the mockup elements, it is logical to think that the boron loading of the four mockup elements collectively might have contained approximately 1/3 gm more B-10 than the four actual elements (based on the 17 cent reactivity difference between the fully loaded cores and a boron worth of 60.3 cents per gram [9]). This is considered a reasonable premise since the relative core positions of these four elements changed as a function of core loading. When criticality was first obtained these four SM-1 and SM-2 elements were on the periphery of a small core and the increased amount of boron would be extremely noticeable. As the loading progressed and core size increased, the relative positions of these elements were displaced toward the center of a larger core and the same boron difference would become less noticeable since the fuel and poison content is known to be identical in both cores for all fuel additions subsequent to the initial loading. This reasoning is substantiated by the fact that the reactivity differences between the estimated and actual five rod bank critical positions for the 5th, 6th and final loading stages decrease to 53, 24 and 17 cents respectively. Part of this reactivity difference may also be attributed to the fact that the two material test elements were loaded first at the site and last during the ZPE; however, this effect is considered negligible since those elements contain no fuel and are located at the periphery of the core.

Figure 3.2.1 is a plot of the actual and estimated five rod bank critical positions Vs the number of elements inserted. Control rods A and B were withdrawn to 19 in. The two material test elements were not considered as fuel elements since they contained no uranium. The two curves presented in Fig. 3.2.1 show the convergence of the estimated and actual critical positions as the core loading progressed.

The five rod bank critical position of 6.53 in. withdrawn for the fully loaded SM-1 Core II was in excellent agreement with the estimated critical position of 6.6 in. This close agreement between actual and estimated critical position indicates that the loading difference assumed to exist between the actual and mocked up SM-1 high burnup and SM-2 fuel elements had little effect on total reactivity in the fully loaded SM-1 Core II.

The startup count rates of Channel 1 (BF_3 #1) tabulated in Table 3.2.1 were about one-third of the estimated values based on measurements at Alco's Critical Facility. [8] This difference in the estimated and actual startup channel count rates is attributed to differences in detector efficiency, uncertainties in the actual startup neutron source strength, and slight differences between the mockup shield and vessel compared to the actual SM-1 installation.

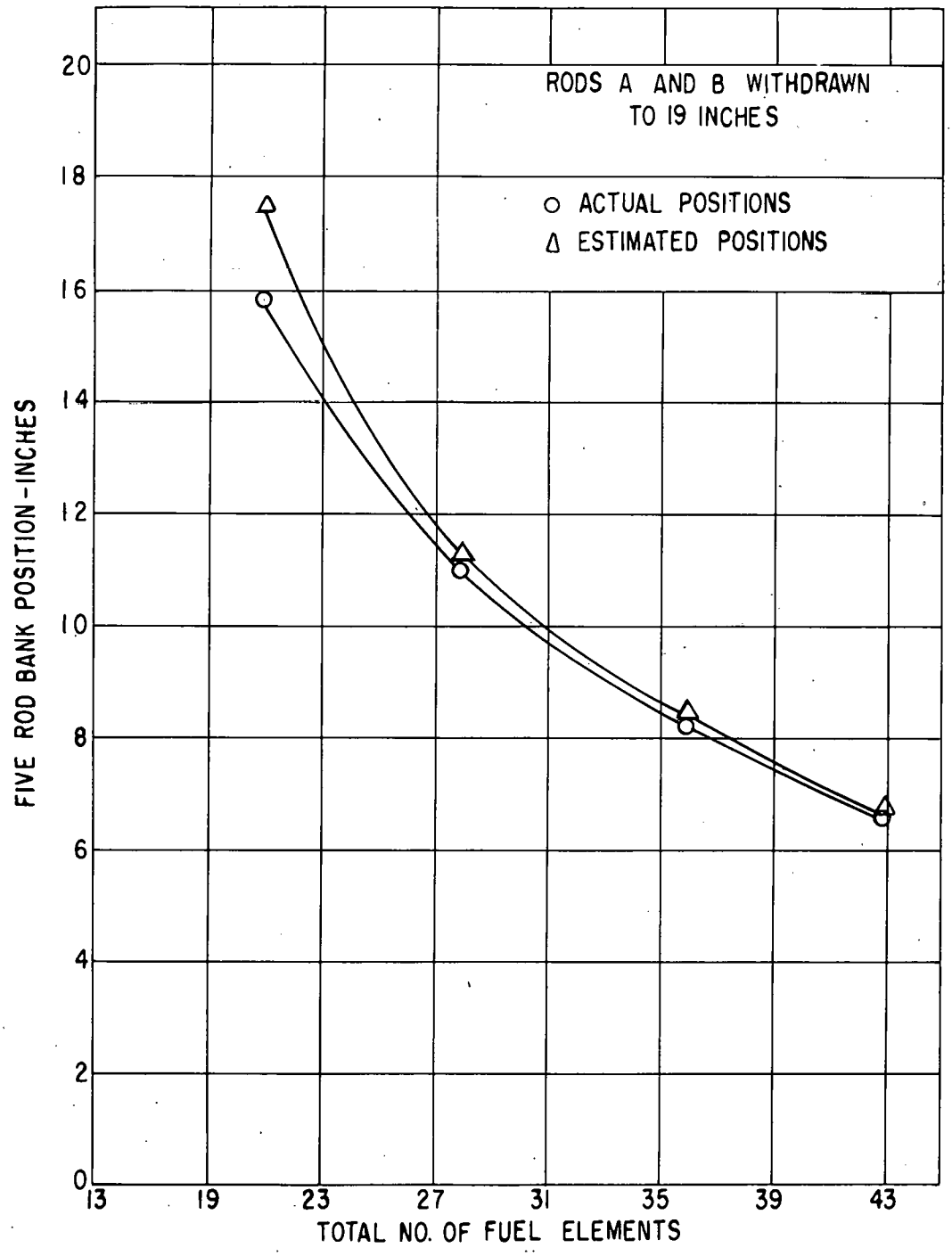

Figure 3.2.1. Critical Five Rod Bank Position Vs. Total Number of Fuel Elements Loaded - SM-1 Core II Loading

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4.0 CORE PHYSICS TESTING

4.1 STARTUP CHANNEL CALIBRATIONS

Voltage and pulse height curves for the startup channels were obtained prior to reactor operations to insure safe and optimum startup channel operation to provide a basis (under cold, clean conditions with a low gamma field) for evaluating the startup channel performance throughout core life. These data are presented in Fig. 4.1.1 and 4.1.2. Based upon these data, operational settings of 1950 volts and pulse height settings of 150 were selected for both startup channel.

The SM-1 is provided with a dual PoBe-SbBe startup source and an auxiliary 3 in. x 3 in. x 0.5 in. beryllium photoneutron source. Characteristics of the dual source are found in reference (5). Since the plant had been shut down for two months prior to core II startup, it can be assumed that the major source contribution is supplied by the startup source.

The difference in magnitude between the responses of the two chambers is attributed to the flux pattern in the core. Using the chamber and associated system circuitry of channel 1 in each well prior to reactor startup, a shutdown flux was revealed which was estimated to be a factor of six higher in well "F" (normally channel 2) than it was in well "B" (normally channel 1).[10] This difference in chamber response is attributed to the difference in the distance from the neutron source for the two positions since the same chamber was used in each position for this measurement.

Startup channel operation data were re-run on June 24 after approximately 625 Mw/hr energy release from Core II. These data are presented in Fig. 4.1.3 and 4.1.4. Due to the Core II gamma ray field, the BF_3 chamber response increased at the higher voltage and lower discriminator settings.

As a consequence, the operating voltages were reduced from 1950 to 1850 on each chamber. The pulse height setting remained at 150 on chamber #2 and was increased from 150 to 200 on chamber #1.

During the August 20-25 shutdown the startup channels were again calibrated. The optimum voltage and pulse height settings were similar to those found June 24.

On the basis of the above measurements, it is concluded that the startup BF_3 chambers operate satisfactorily. However, in order to properly adjust the operating parameters to compensate for gamma radiation, thermal, and aging effects on the chambers, and to detect any electronic difficulties, it is recommended that calibrations be performed prior to all startup operations as a routine matter.

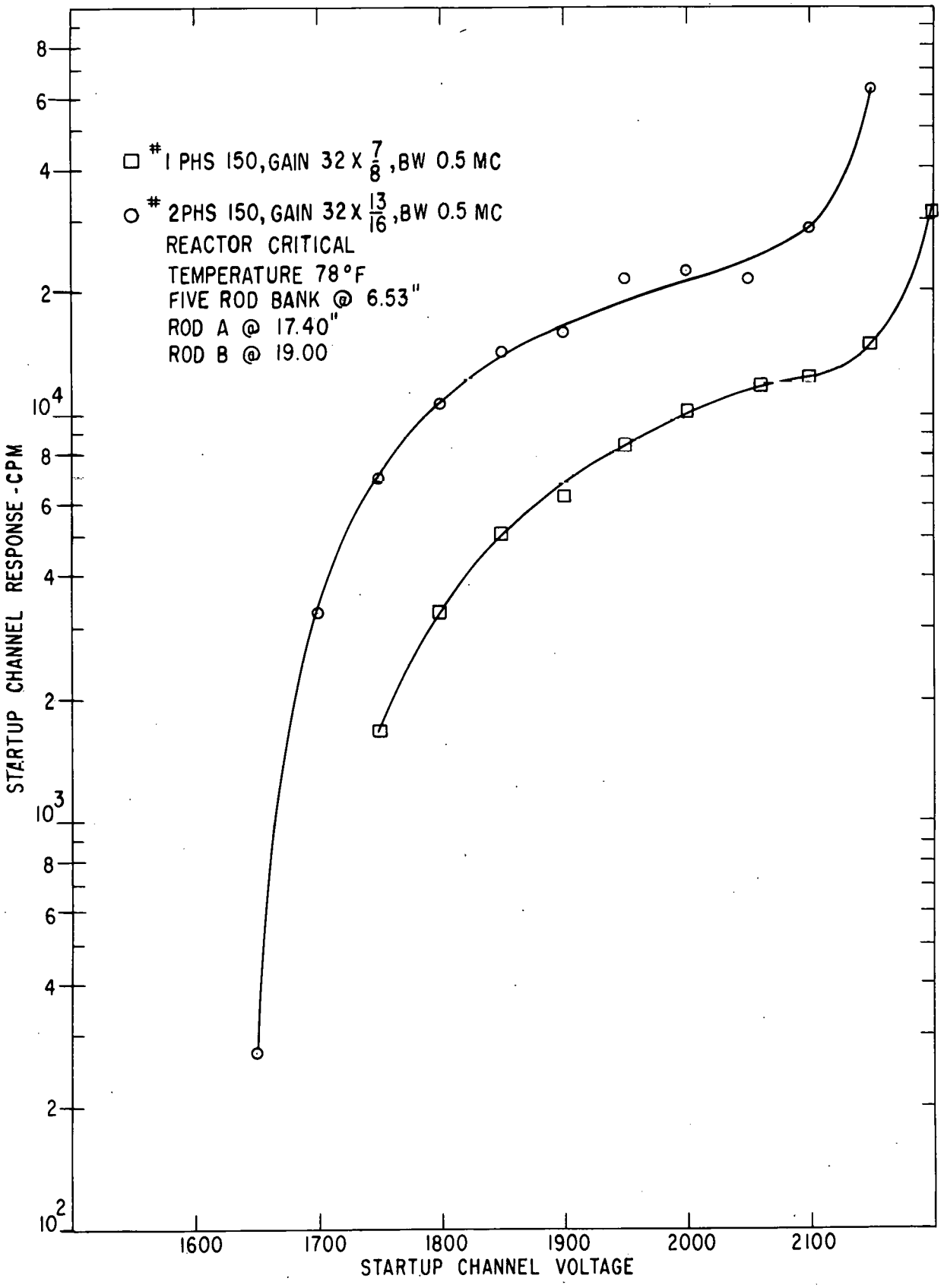

Figure 4.1.1. SM-1 Core II Startup Channel Voltage Calibration (June 4, 1961)

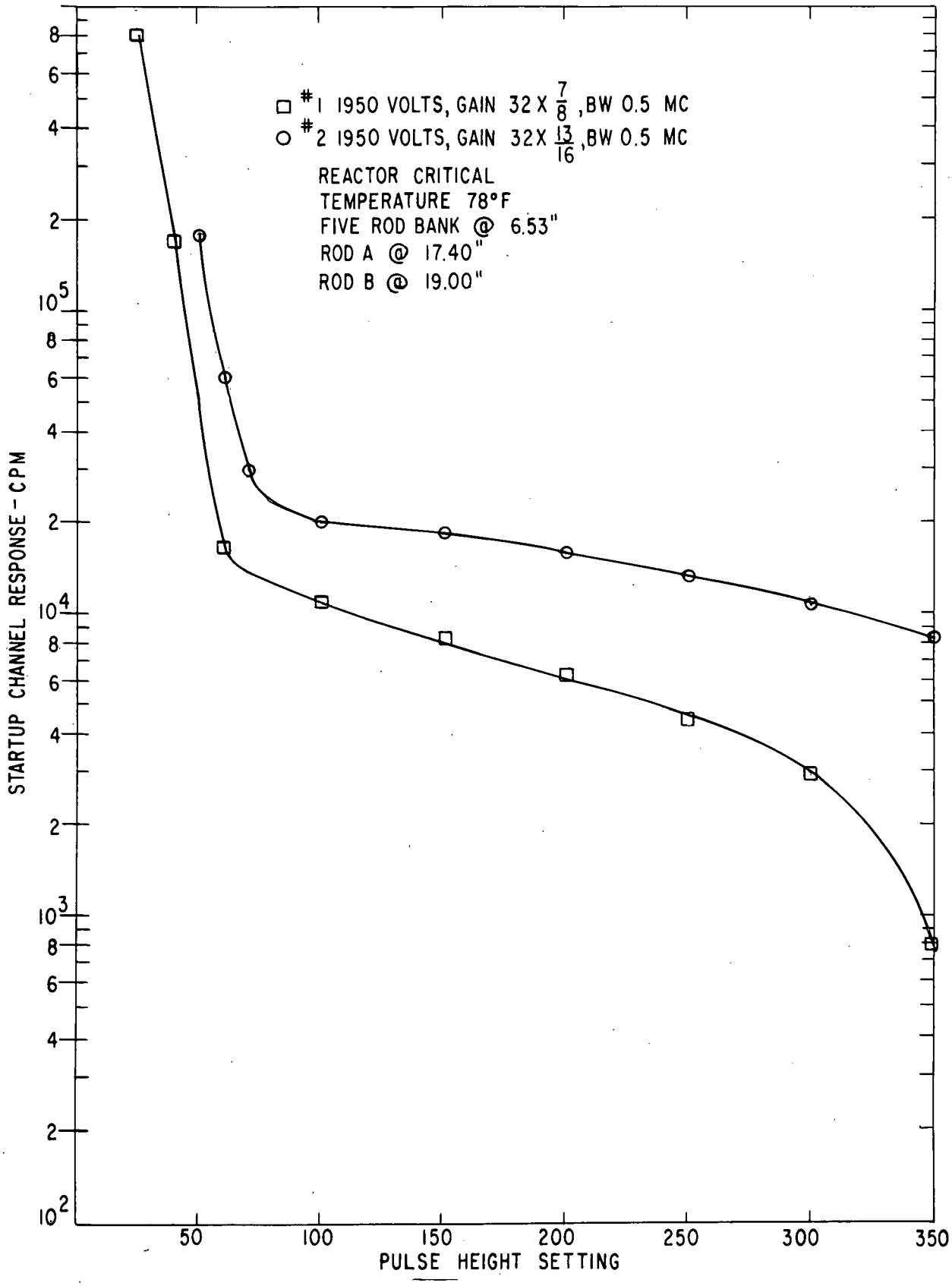

Figure 4.1.2. SM-1 Core II Startup Channel Pulse Height Calibrations (June 4, 1961)

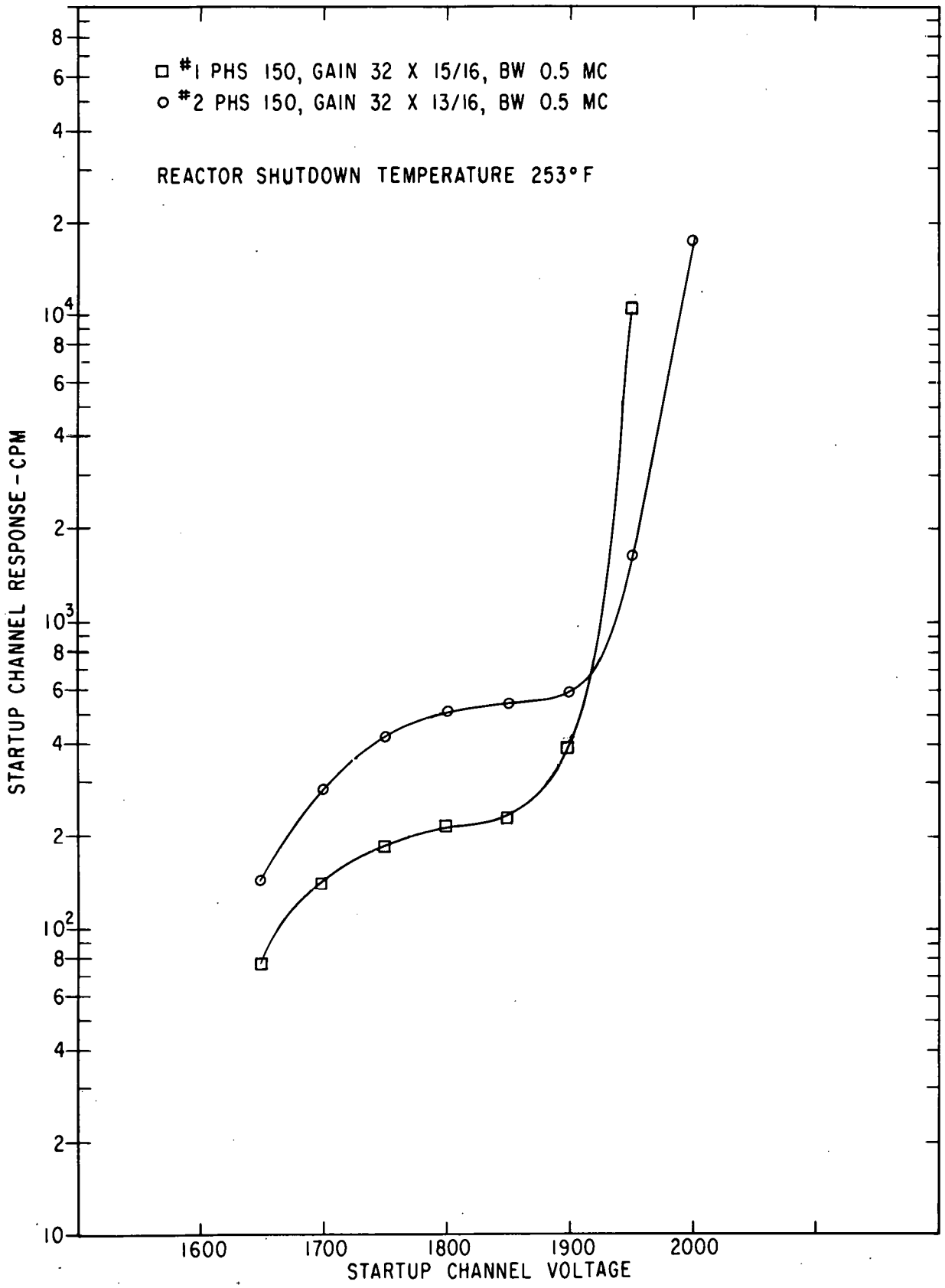

Figure 4.1.3. SM-1 Core II Startup Channel Voltage Calibrations (June 24, 1961)

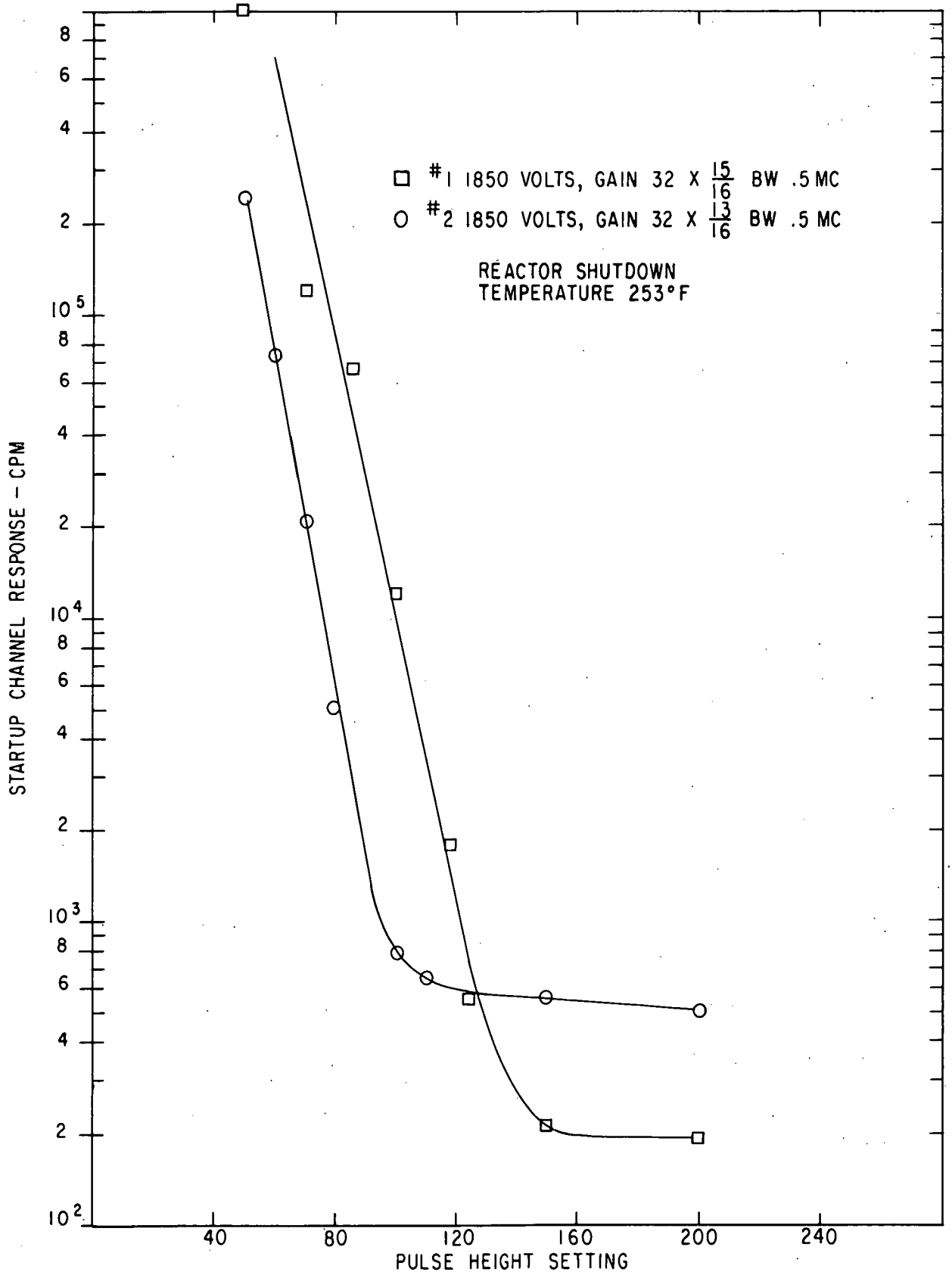

Figure 4.1.4. SM-1 Core II Startup Channel Pulse Height Calibrations (June 24, 1961)

4.2 FIVE ROD BANK POSITIONS

Five rod bank positions (with rods A and B at 19.00 in.) were obtained during the initial Core II startup. These data are listed in Table 4.2.1.

TABLE 4.2.1
FIVE ROD BANK POSITIONS (INCHES)

Energy Release	Cold Low Xe	440°F Low Xe	440°F Equil. Xe	440°F Peak Xe
0.000 MWYR	6.53 (78°F)	9.62		
0.076			11.41	12.14
0.302			11.54	12.30
0.878	6.85 (111°F)	9.86		
1.228			11.83	12.57

Due to training operations, attempts to measure the reactivity effect of samarium buildup were invalidated. A constant core temperature did not exist long enough to allow the appropriate data to be collected.

4.3 STUCK ROD MEASUREMENTS

Extensive work was performed during the SM-1 Core II Zero Power Experiments [1] in order to establish the critical positions of various rod configurations and hence determine whether the minimum stuck rod requirments of the SM-1 could be met with Core II. Results of the ZPE indicate that the core can be shut down with 80% of the rods fully inserted.

At the time of the startup tests for the SM-1 Core II there was no opportunity to check the ZPE work at low temperature. However, several typical rod configurations were checked at higher temperatures, the results of which are listed in Table 4.3.1. Measurements in cases 1-8 were obtained at a core temperature of 224°F; measurements in cases 9-11 were obtained at a core temperature of 111°F.

TABLE 4.3.1
CRITICAL ROD CONFIGURATIONS

	Rod Positions in Inches Withdrawn						
Case	Rod A	Rod B	Rod C	Rod 1	Rod 2	Rod 3	Rod 4
1	22.12	0	22.01	0	0	0	13.19
2*	22.12	22.08	0	22.10	0	0	0
3	22.12	0	0	22.10	0	0	11.04
4	22.12	0	0	22.10	13.19	0	0
5	22.12	0	11.17	22.10	0	0	0
6	22.12	0	12.00	19.00	0	0	0
7	19.00	0	12.24	19.00	0	0	0
8*	22.00	0	0	0	0	0	22.15
9	22.10	19.00	0	0	0	0	18.85
10	22.10	12.31	0	0	0	0	22.12
11	22.10	0	7.90	22.12	0	0	0

* These cases subcritical

In order to compare the ZPE and plant data properly, corrections must be applied to account for two distinct effects:

1. The ZPE data was obtained without the 50 mil steel skirt on the core. Therefore, the SM-1 core with the skirt attached will be 56 cents[1] less reactive than the ZPE core.

2. The ZPE data was obtained at 68°F while SM-1 data was obtained at considerably higher temperatures. Due to the temperature coefficient, it is estimated the SM-1 core is 150 cents less reactive at 224°F and 20 cents less reactive at 111°F when compared with the ZPE core at 68°F.

As a result of the above effects, the SM-1 critical positions should be higher than the comparative ZPE positions to account for 206 cents at 224°F and 76 cents at 111°F. Using the single point rod worths obtained during the ZPE stuck rod experiments and the difference between the ZPE and site measurements, it is estimated that the reactivity loss between 68°F over 224°F amounted to approximately 150 cents and that at 110°F amounted to approximately 55 cents. Considering that the on-site data was taken at an elevated temperature compared to the ZPE and that the data correlation is based upon a single point rod calibration, the lack of quantitative agreement is expected. However, the general conclusion that the SM-1 Core II may be shut down with 80% of the control rods inserted is valid.

4.4 ROD CALIBRATIONS

Using the period method, calibrations were obtained for control rod A, rod C, and the five rod bank respectively during the Core II startup testing period. These calibrations, presented in Fig. 4.4.1 thru 4.4.5 are least square (second order) polynomial fits of the data points. The data is tabulated in Tables 4.4.1 thru 4.4.5. Comparable SM-1 Core I calibrations are also shown by broken lines for several cases.[3] Inspection of the various cases reveals that the Core II control rod calibration peak has shifted and broadened somewhat compared to the Core I curves.

Factors which have been suggested as possible causes for these effects are the integral flux suppressors in the top of the control rod fuel elements which have been observed to shift the calibration curve[1] and the presence of the high burnup fuel elements in the center region of the core which permits a higher neutron flux level and consequently a higher rod worth extending over the region of fuel depletion.

If one examines the core configuration of Figure 4.1.1, it appears that the five rod bank calibration should show the effect of increased rod worth due to the proximity of all five rods in the bank to the high burnup elements. The rod A calibration is less affected since it is not directly adjacent to the high burnup elements and consequently is not in the region of the maximum flux perturbation.

As a result of these observations it is recommended that both rods A and B be calibrated individually during the next core physics testing period to measure the effect of these elements on the rod calibrations. Since rod A is separated from the high burnup elements and rod B is adjacent to two of them, a difference measurement would help to explain this effect.

Figure 4.4.6 illustrates the calculated relative thermal neutron flux in the core. The calculation is based on the square root of the rod A calibration at 440°F averaged over the core height (22 in.) and normalized to unity. The peak neutron flux is not as high relative to an average of unity over the rod travel as that observed in similar Core I measurements; however, the small difference is attributed to the broadening of the Rod A calibration peak in Core II.

The estimated excess reactivity in the core at equilibrium xenon is approximately $10.00 based on an extrapolation of the five rod bank calibration of Fig. 4.4.5. This compares with $12.9 estimated at startup of Core I.[3]

TABLE 4.4.1
SM-1 CORE II ROD A CALIBRATION, 440°F, NO XENON, O MWYR.
ROD B AT 19.00 INCHES. FIVE ROD BANK 9.62-12.20 INCHES

Rod A Position Inches	Rod A Worth cents/inch
16.34	7.75
13.95	16.05
11.41	26.10
9.53	41.90
8.10	46.70
7.14	47.70
6.27	42.40
5.20	34.90
3.23	25.50
1.57	16.20

TABLE 4.4.2
SM-1 CORE II ROD A CALIBRATION, 77°F, NO XENON, O MWYR.
ROD BE AT 19.00 INCHES. FIVE ROD BANK 8.21-6.52 INCHES

Rod A Position Inches	Rod A Worth cents/inch
1.08	12.00
2.61	19.20
3.67	26.20
5.36	34.20
6.84	27.60
8.38	29.60
9.99	24.10
11.64	16.90
14.09	11.00
17.49	3.95

TABLE 4.4.3

SM-1 CORE II ROD A CALIBRATION, 440°F, PEAK XENON, O MWYR.
ROD BE AT 19.00 INCHES. FIVE ROD BANK 12.13-14.52 INCHES

Rod A Position (inches)	Rod A Worth (cents/inch)
6.57	34.30
4.38	27.00
8.25	39.20
10.34	35.90
12.35	28.40
14.78	14.50
18.42	3.10
17.51	5.25

TABLE 4.4.4

SM-1 CORE II ROD C CALIBRATION, 440°F, NO XENON, O MWYR.
RODS A AND B AT 19.00 INCHES. FOUR ROD BANK 7.94-12.63 INCHES

Rod C Positions (inches)	Rod C Worth (cents/inch)
0.86	17.20
2.42	32.50
3.75	44.60
5.19	66.60
8.17	62.50
9.70	63.60
11.28	39.60
13.48	28.80
15.84	14.70
17.45	13.60
18.86	11.50
4.70	44.00
6.17	60.00
7.66	63.50
9.19	53.00

TABLE 4.4.5
SM-1 CORE II FIVE ROD BANK CALIBRATION, O MWYR.
RODS A & B AT 19.00 INCHES

Five Rod Bank Position (In.)	Five Rod Bank Worth (¢/In.)	Core Temp. (°F)	Xenon Condition
6.585	245	77	No xenon
6.591	212	77	No xenon
6.587	227	77	No xenon
6.578	265	77	No xenon
7.855	248	300	No xenon
7.855	239	300	No xenon
7.853	250	300	No xenon
7.842	235	300	No xenon
7.053	226	200	No xenon
7.057	212	200	No xenon
7.053	216	200	No xenon
9.632	257	440	No xenon
9.634	212	440	No xenon
9.579	252	440	No xenon
14.560	114	440	Peak xenon
14.578	154	440	Peak xenon
12.524	197	440	Peak xenon
12.516	164	440	Peak xenon
12.573	162	440	Peak xenon
12.521	158	440	Peak xenon
7.270	235	220	Low xenon
7.293	240	220	Low xenon
7.298	251	220	Low xenon
7.312	221	220	Low xenon

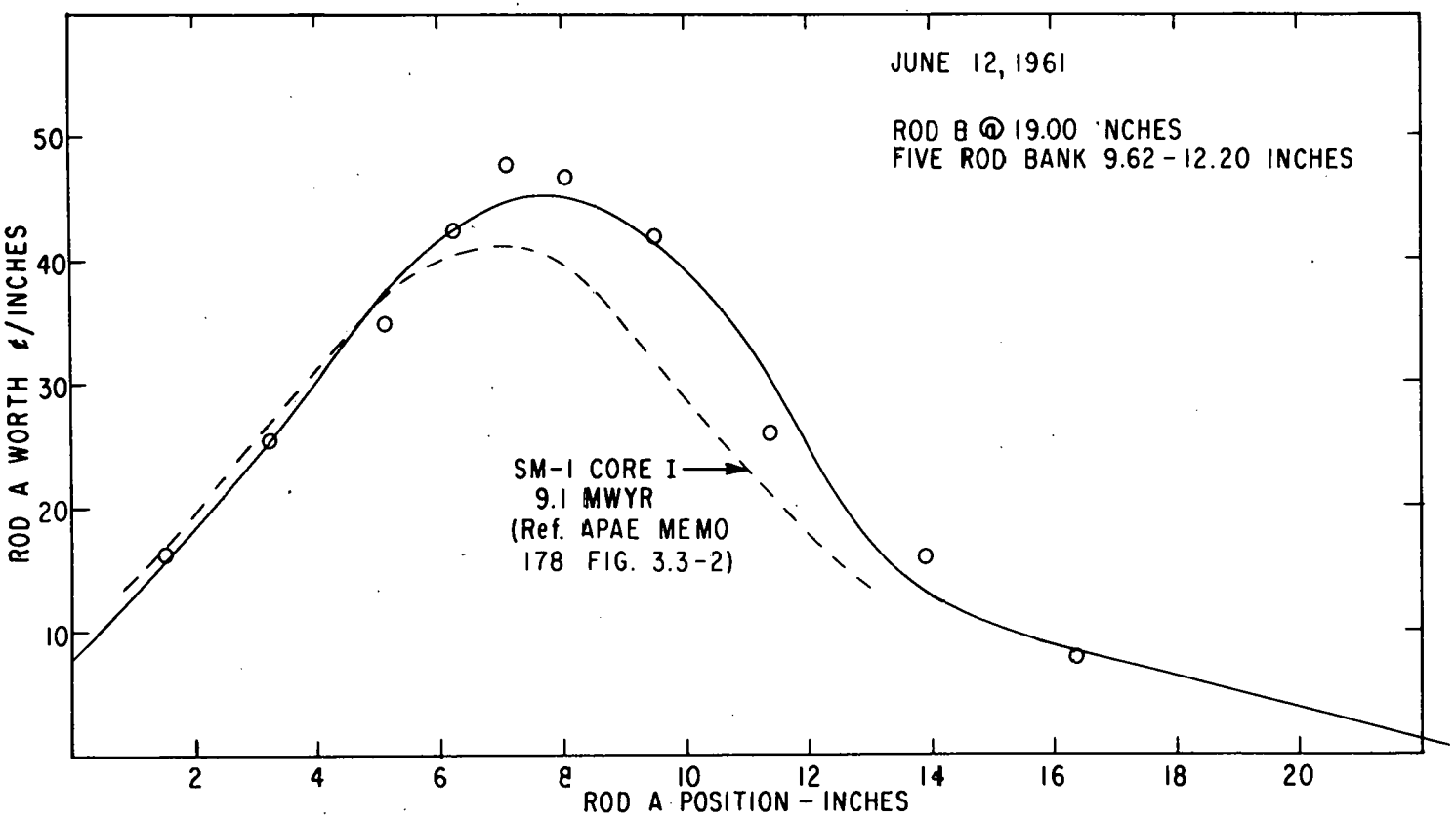

Figure 4.4.1. SM-1 Core II Rod A Calibration 440°F No Xenon, 0 MWYR

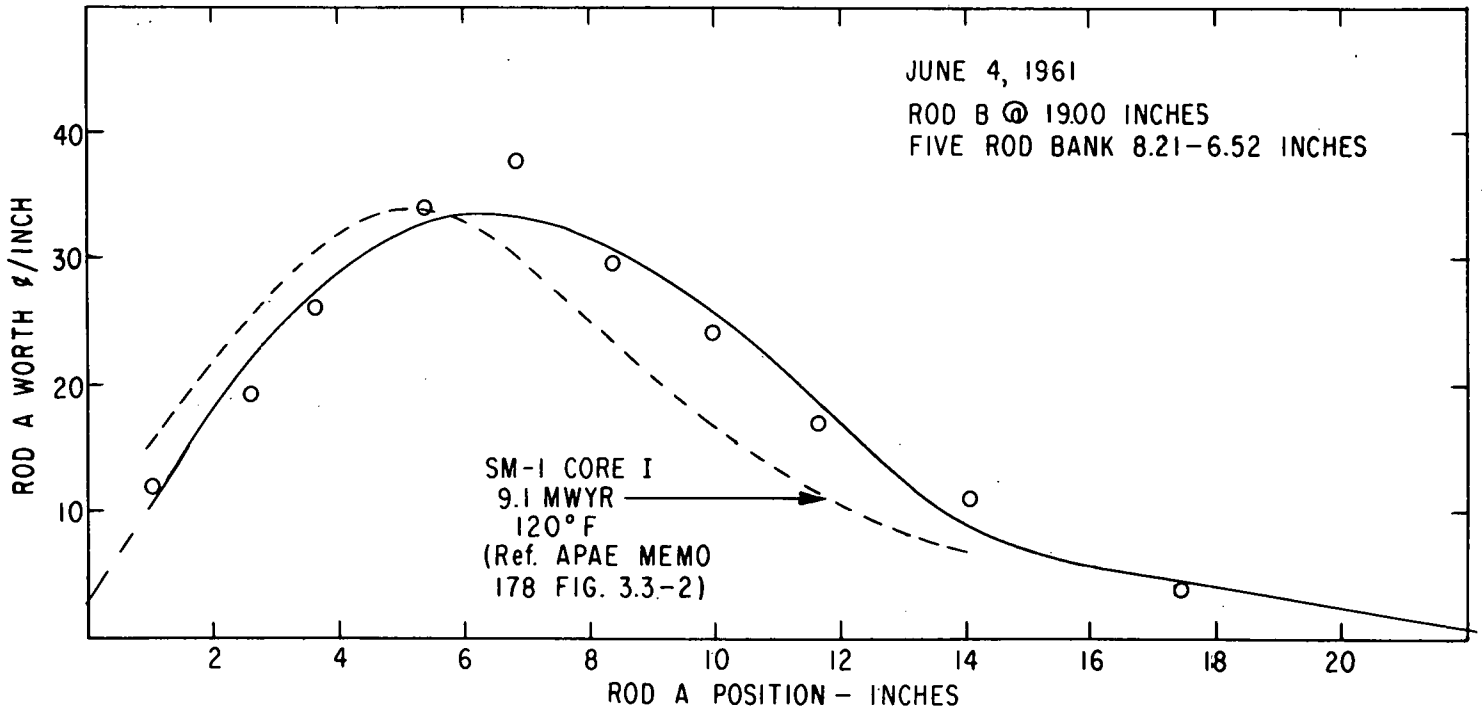

Figure 4. 4. 2. SM-1 Core II Rod A Calibration 77°F No Xencn, 0 MWYR

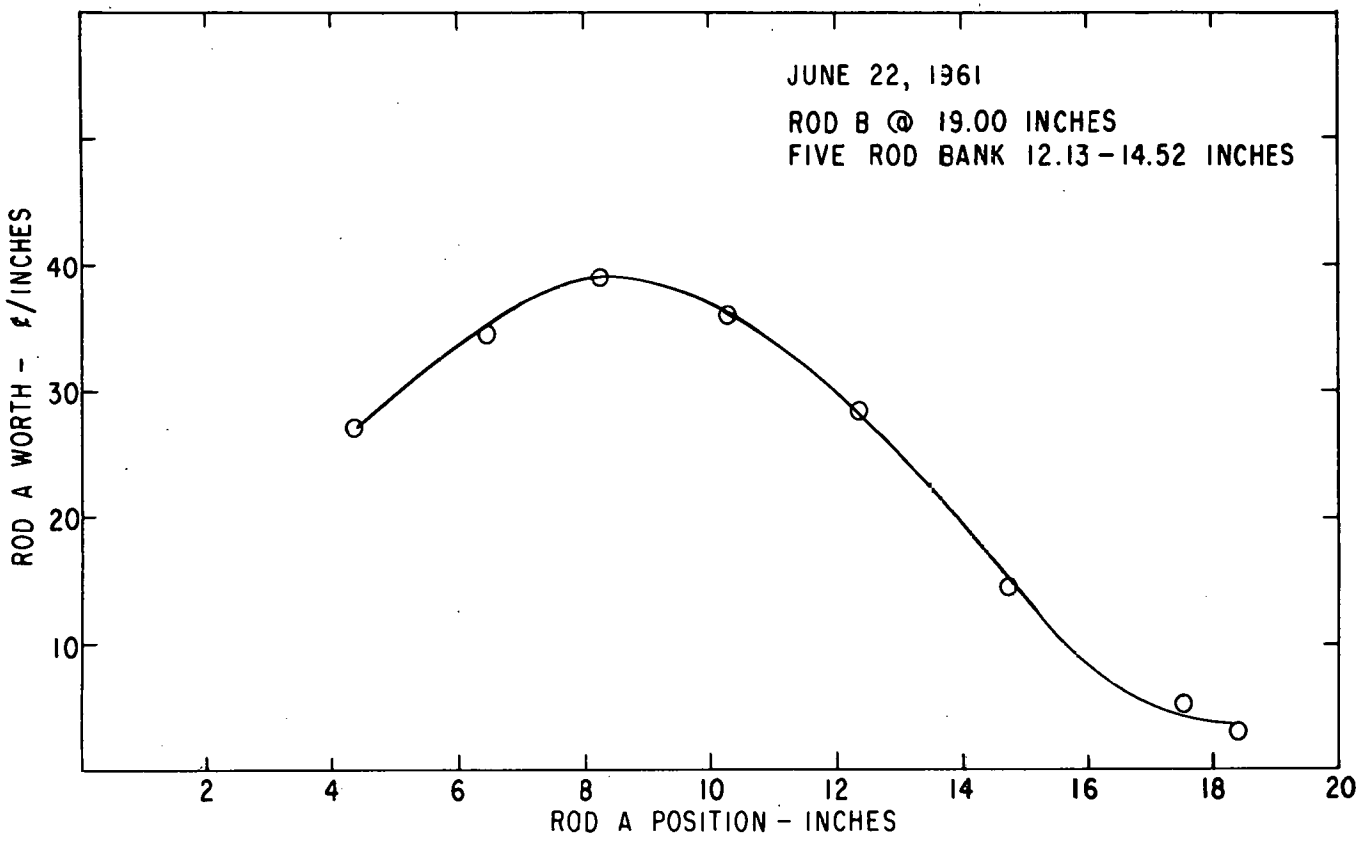

Figure 4.4.3. SM-1 Core II Rod A Calibration 440°F
Peak Xenon, 0 MWYR

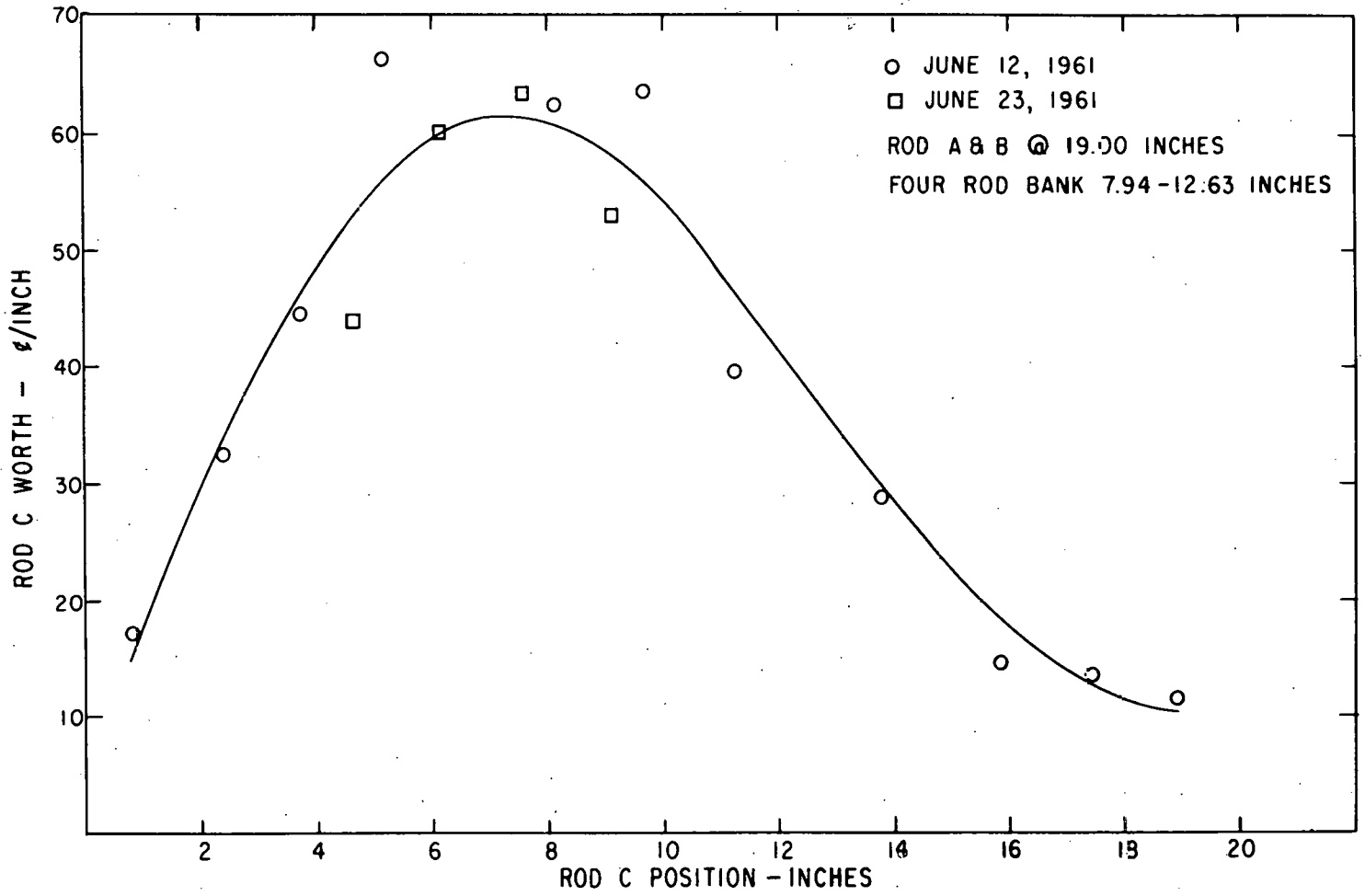

Figure 4.4.4. SM-1 Core II Rod C Calibration 440°F
No Xenon, 0 MWYR

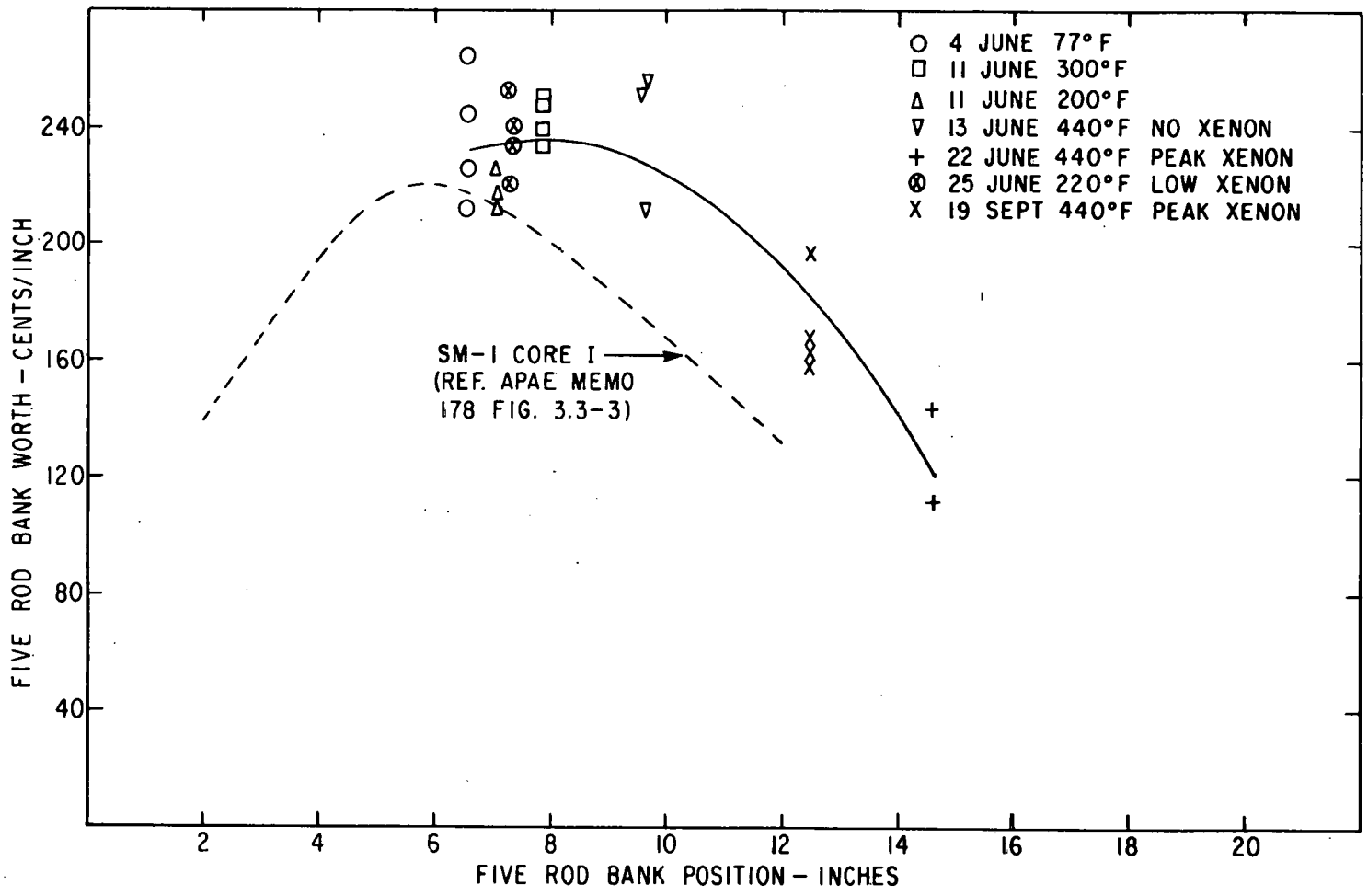

Figure 4.4.5. SM-1 Core II Five Rod Bank Calibration, 0 MWYR

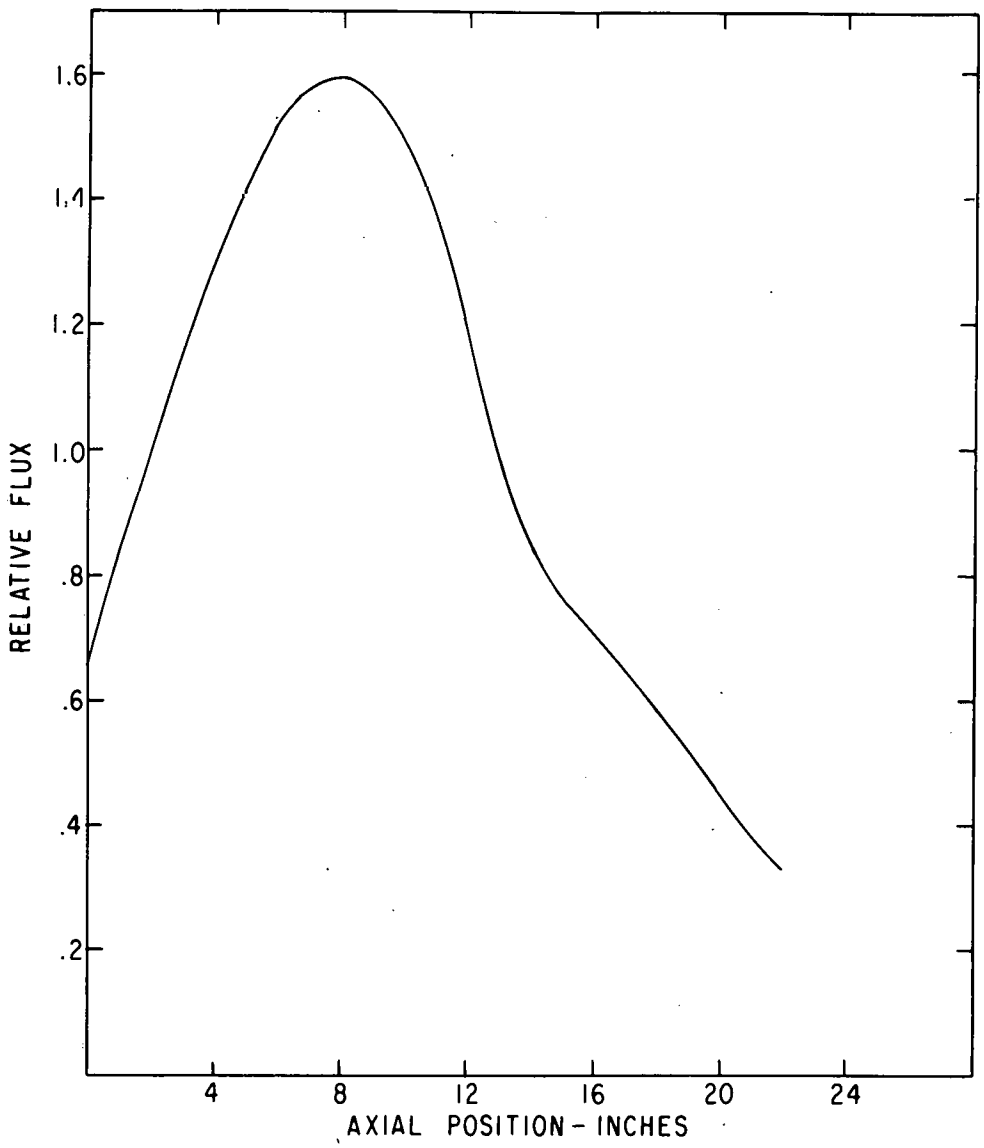

Figure 4. 4. 6. Relative Thermal Neutron Flux SM-1 Core II, 0 MWYR

4.5 TEMPERATURE COEFFICIENT

Temperature coefficient measurements were obtained once during the initial heatup and once during a cooldown period. The reactivity associated with the change in temperature was measured on precalibrated rod A. The temperature coefficient data is presented in Fig. 4.5.1 and Table 4.5.1.

TABLE 4.5.1
SM-1 CORE II TEMPERATURE COEFFICIENT, O MWYR

Temperature (^{O}F)	Temperature Coeff. (cents/^{O}F)
119	.29
144	.87
171	.95
186	1.36
199	1.09
209.5	1.71
225	1.60
242	1.73
254	1.67
264	1.62
280	1.78
296	2.12
386	3.09
408	3.40
448.5	3.33
445	3.45
444.5	3.64
433.5	3.33
346.5	2.85
334.6	2.79
320.0	2.60
304.5	2.17
295.5	2.24
286.0	2.10
275.0	1.98
261.5	2.02

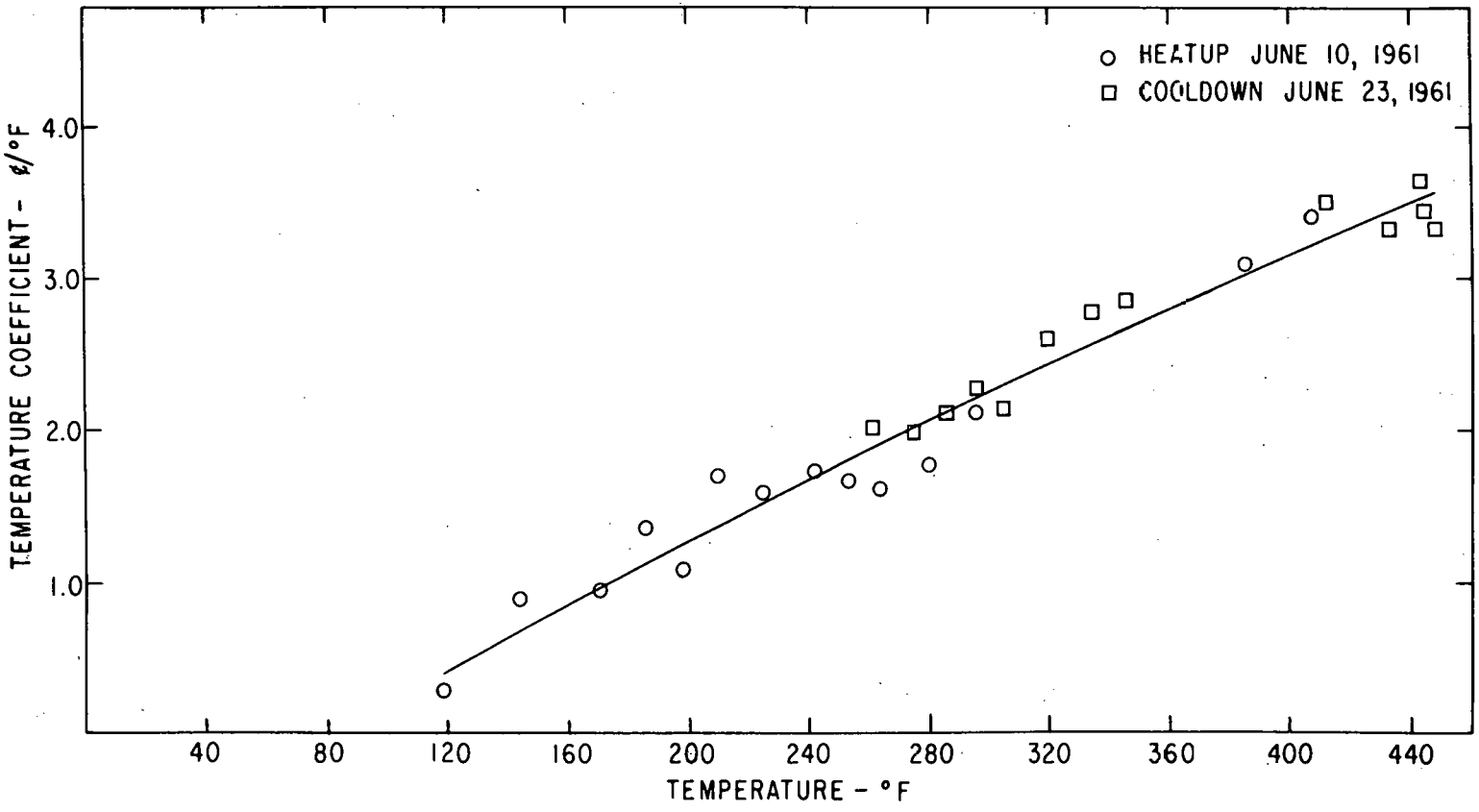

Figure 4.5.1. SM-1 Core II Temperature Coefficient, 0 MWYR

The total temperature defect obtained by integrating under the curve of Fig. 4.5.1 is $6.50. The total temperature defect based on integration under the five rod bank calibration curve (Fig. 4.4.5) between the cold clean and hot no xenon bank positions renders a temperature defect of $7.20. The two results agree within 10% and since there is a large uncertainty associated with these measurements, the agreement is considered acceptable. The value measured for SM-1 Core I at O MWYR was $7.15 $\pm$ .20[3].

4.6 TRANSIENT XENON

The reactivity effect of xenon buildup and subsequent decay was determined based on the five rod bank movement. The position of the five rod bank as a function of time is shown in Fig. 4.6.1 and data is tabulated in table 4.6.1. This curve and the curve of the five rod bank calibration (Fig. 4.4.5) were used to calculate the reactivity effect of xenon as a function of shutdown time. The results are presented in Fig. 4.6.2. The value for peak xenon is $1.43 relative to equilibrium Xe which is in excellent agreement with the peak value of $1.50 measured for Core I.

The reactivity effect of equilibrium xenon from Fig. 4.6.2 is approximately $3.00. The values measured for SM-1 Core I at O MWYR were $3.52 and $1.33 for equilibrium and peak xenon respectively.[3]

TABLE 4.6.1
FIVE ROD BANK MOVEMENT DURING XENON BUILDUP AND DECAY
SM-1 CORE II, O MWYR

Time After Shutdown (Hr)	Five Rod Bank Position (In.)
0	11.41
9.2	12.07
15.2	11.64
20.1	11.27
23.2	11.04
27.5	10.71
31.3	10.45
36.7	10.17
41.0	10.03
42.2	9.98

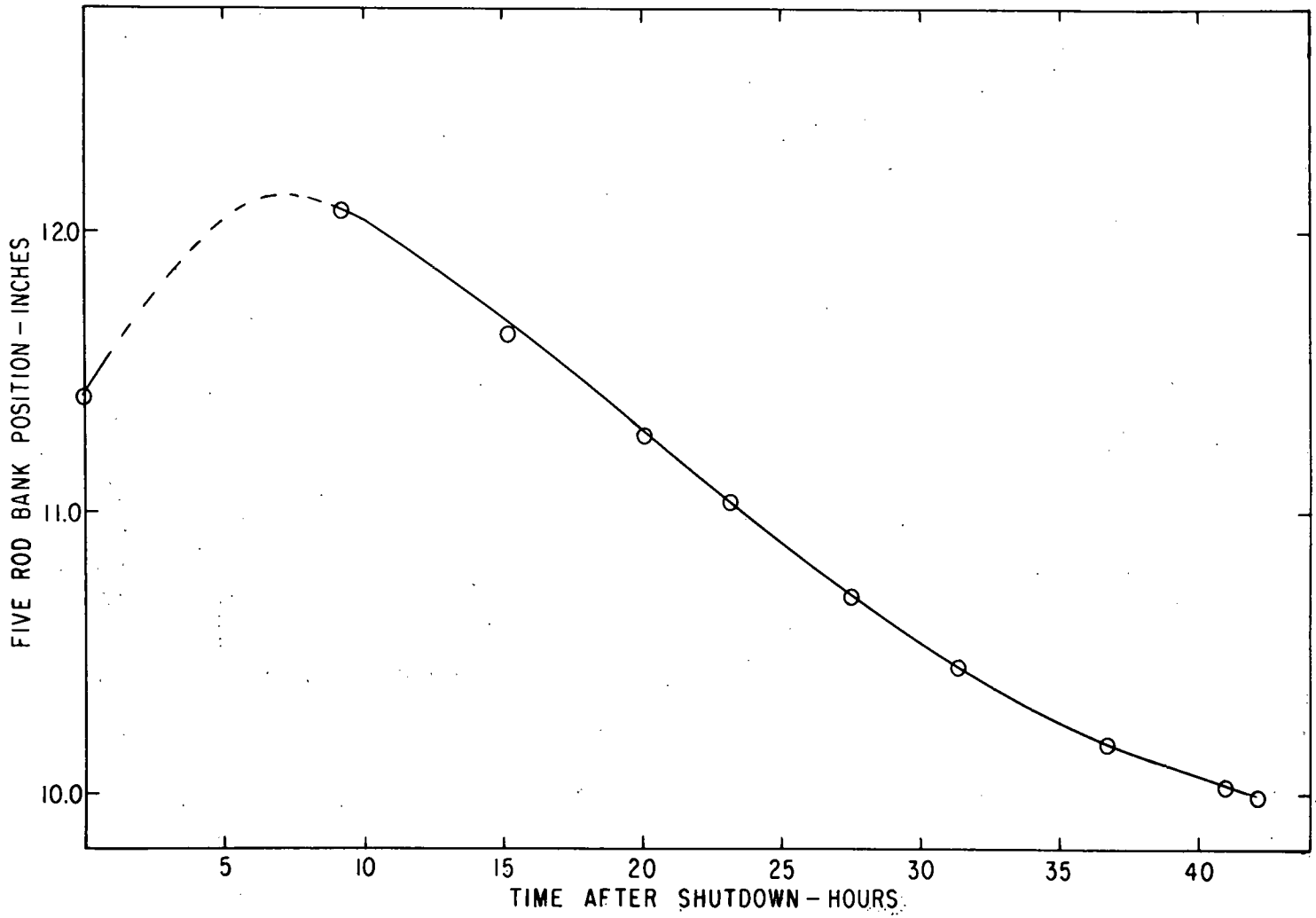

Figure 4.6.1. Five Rod Bank Movement During Xenon Buildup and Decay SM-1 Core II, 0 MWYR

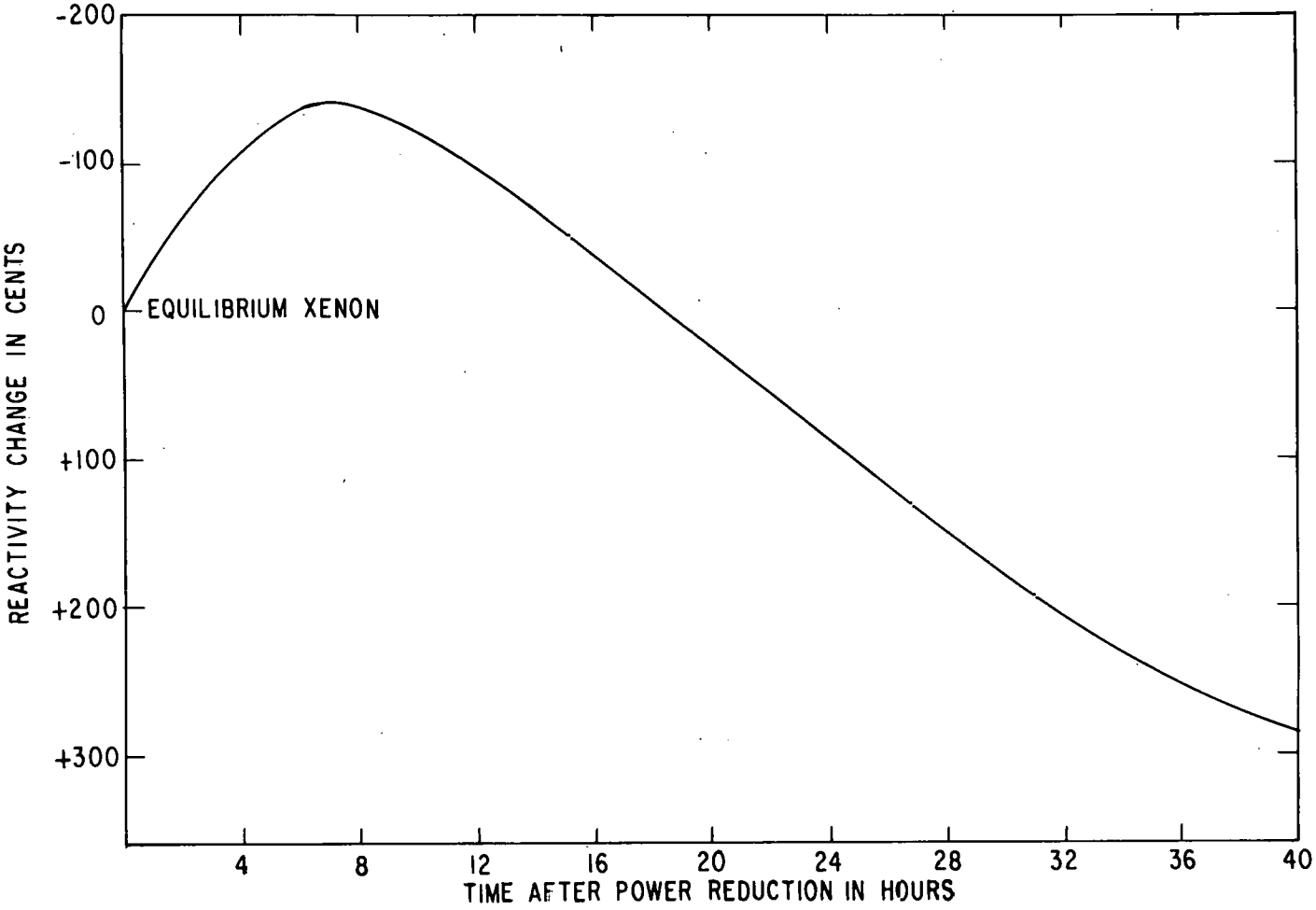

Figure 4.6.2. SM-1 Core II Xenon Reactivity Effect, 0 MWYR

5.0 FISSION PRODUCT IODINE MONITORING

The gross fission product iodine levels in the SM-1 coolant were measured frequently since Core II startup. Two methods of determining the gross iodine levels were employed: 1) An ion exchange-gamma spectrometer method; and 2) a radiochemical separation - G-M tube method. The ion exchanger-gamma spectrometer method is accomplished by adding 2-3 drops of HC1 to a 50 ml sample of primary water. The acidified sample is passed through a cation exchange column at the rate of approximately 3 ml/min. After 10 ml of the sample has passed through the column, a 3 ml sample is collected in a counting vial. Exactly 20 minutes after extraction from the primary system the sample is counted on a single channel gamma ray spectrometer; integrating all pulses with energies greater than 1.4 Mev. This method results in the detection and counting of gamma photons of essentially only the iodine isotopes. The results of this method are reported in counts per minute (cpm), since a gamma standard which would simulate the gamma photon emission of a mixture of iodine fission products was not available. The ion exchange-gamma spectrometer method was also used during Core I operation.

In order to relate the fission product monitoring results of the SM-1 to other Army nuclear power reactors, the radiochemical separation - G-M tube method of test procedure TP-A-200 (shipboard procedure) was initiated at warmup of Core II. This method entails mixing of the heated primary water with a AgI precipitate. The gross iodine concentration is determined by isotopic exchange. The radioactive iodine in a coolant sample is exchanged for inactive iodine by contacting the sample with preformed AgI. Before mixing the coolant and AgI precipitate, the radioiodine in the coolant is oxidized to periodate (IO_3^-) followed by reduction to iodide (I^-). This step is necessary to insure complete exchange between radioactive and stable iodide. The primary sample containing radioiodine is added to the AgI precipate and the two are mixed intimately. The precipitate is filtered onto a 24 mm filter disc which is mounted in a nickel planchet, dried, and counted in a beta counter exactly 45 min after sampling from the primary system. The results of this method are reported in dpm (disintegrations per minute). A Sr^{90}-Y^{90} standard source is used to convert the cpm of the sample to dpm. For reliable results, a more exact chemical technique is required for the radiochemical separation method as compared to the faster and simpler ion exchange method.

Differences in the results of the two methods can be traced to the technique of different chemists. A typical example is shown in Fig. 5.1, where it is seen that the results of the radiochemical separation method vary somewhat more than the results of the ion exchange method during a day when the reactor was at a constant power level. For example, on June 20, 1961, the results of the radiochemical separation method varied from about 2×10^4 to 8×10^4 dpm/ml, or a factor 4, during the same day, the results of the ion exchange technique varied

from about 3×10^3 to 6.5×10^3 cpm/ml, or a factor of about 2.2. Similar differences are found for other sampling dates. In the future, it is planned to utilize the same chemist for all analyses in order to minimize the scatter of the data. Fig. 5.1 also shows that since Core II startup on June 12, 1961, the gross fission product iodine levels, as determined by the ion exchange technique, have reached a maximum of 9780 cpm. On June 21, 1961, after the reactor had been operating at full power for about 1-1/2 days, a fission product level between 6000 to 7000 cpm was found. During Core I operation, on March 27, 1961, during similar operating conditions, the gross fission product iodine level was 19,930 cpm. Thus, gross fission product iodine levels during Core II operation to the end of June, 1961, were about one-third to one-half those levels found during Core I operation.

Figure 5.2 shows the results of gross fission product iodine analyses during July, August and September, 1961. The levels as found by the two methods are about the same as those found during June, 1961. The ion exchange technique has not been used since July 27th, due to malfunctioning of the gamma spectrometer. The bar graph at the bottom of Fig. 5.1 and 5.2 represents the power output of the generator during one day. The theoretical yield of the generator is 24 hr x 2000 kw = 48×10^3 kwh. The broken line at the bottom of the graphs represent the radiation level (mr/hr) measured at the fence around the primary makeup tank approximately 5 ft from the bottom of the makeup tank. The highest meter reading found during the day is the one that is plotted.

In summary, during four months of Core II operation, gross fission product iodine activity levels in the range of 7×10^3 cpm/ml for the ion exchange method, and 7×10^4 dpm/ml for the radiochemical separation method, were measured. These values are about one-third to one-half those found toward the end of Core I operation.

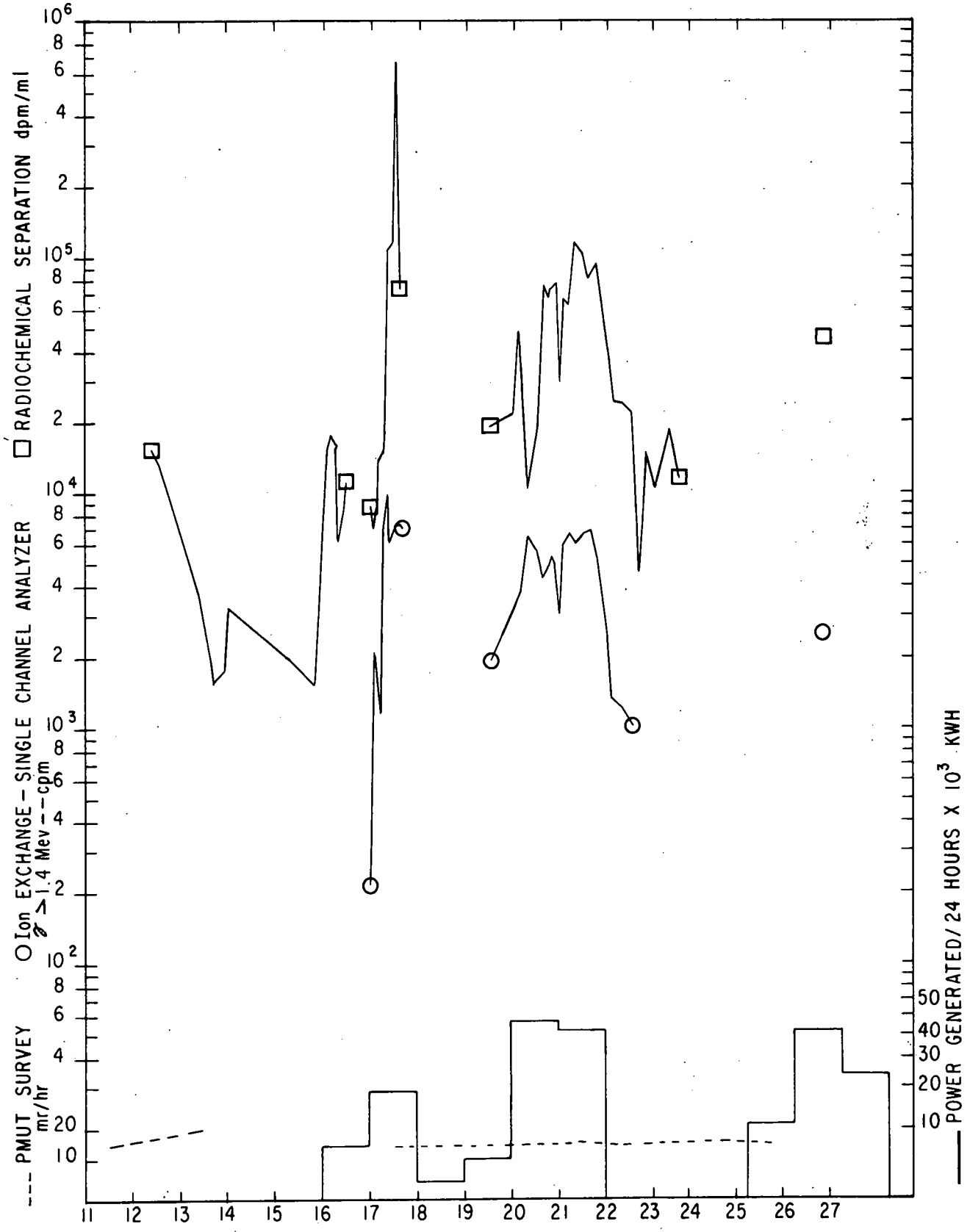

Figure 5.1. Gross Fission Product Iodine Levels in SM-1 Coolant During June, 1961

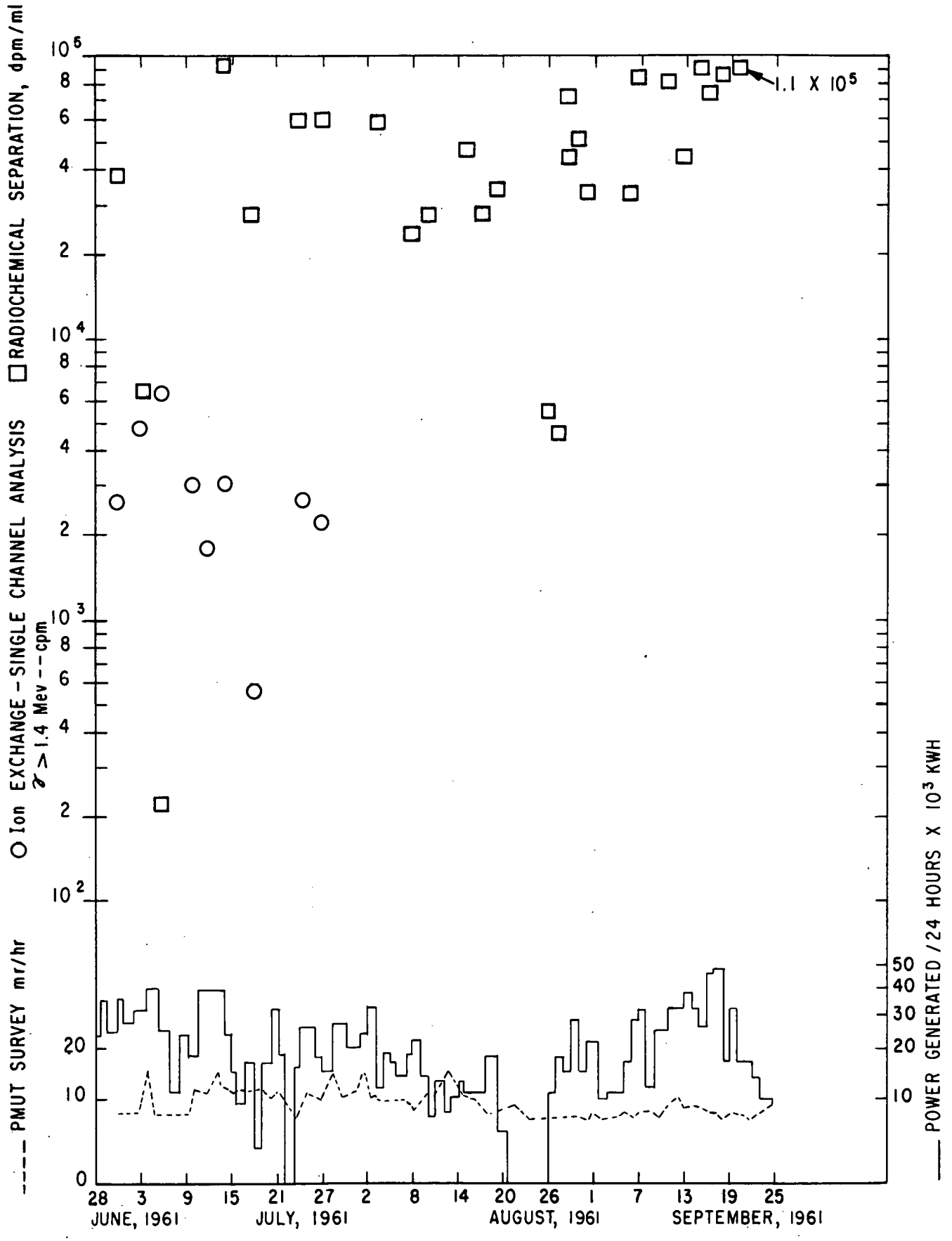

Figure 5.2. Gross Fission Product Iodine Levels in SM-1 Coolant from June to September, 1961

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

1. Core II performance is satisfactory and operating characteristics are only slightly different from those recorded for Core I. (3), (12)

2. Operation of startup channels appears to be satisfactory. However, significant drift is observed between calibrations.

3. Stuck rod measurements show adequate shutdown with 80% of the rods inserted.

4. Control rod calibrations for Core II rods have shifted and broadened compared to similar calibrations obtained for Core I.

5. Core II temperature coefficient data is in agreement with Core I data within the limits of experimental error.

6. No change has been found in the xenon reactivity effects as a result of the core change-over. Moreover, the xenon coefficient of reactivity is considered to be well defined. Therefore, it is felt that less emphasis can be placed on additional xenon measurements with the present SM-1 fuel loading.

7. Gross fission product iodine levels in Core II are a factor of 2 or 3 lower than those found in Core I.

6.2 RECOMMENDATIONS

1. Chamber response in the startup channels varies significantly over the temperature and power range of power reactor operations, and is probably due to several factors; gamma ray pile up, radiation damage, aging, thermal effects, etc. It is recommended that the startup channels be recalibrated (run voltage and pulse height curves) and optimum settings determined prior to all reactor startups. These settings should be logged and used as a guide for future shutdown and startups.

   Voltage curves are obtained by setting the pulse height at a setting above the amplifier noise level and plotting CPM versus voltage over the range 1500-2200 volts. The proper voltage is chosen as the middle of the flat region of the voltage curve (approximately 18-1950 volts). With proper voltage setting, the PHS curve is then

determined by plotting CPM versus PHS setting. The optimum PHS setting is that position on the curve where the neutron noise (or gamma) contribution is a factor on the order of 100 to 1.

2. Least-squares fits were applied to rod calibration and temperature coefficient data for the purpose of establishing a uniform system for drawing the curves. Further work is recommended because of the sensitivity of the fit to the order of the polynomial.

3. An attempt should be made to improve the accuracy of temperature coefficient measurements, since temperature effects are a prime consideration in plant efficiencies and operational lifetime (especially on cores of very high operating temperatures and pressures). More precise temperature sensing elements are needed at the SM-1 along with improved techniques of measurement.

4. As a result of the changes noticed in rod calibrations between Core I and Core II, additional studies of these rod worth variations are desired in order to evaluate the effect of Core II special components. The following rod calibrations are recommended:

   a. Rod A and rod B individually with present core configuration;

   b. Rod A and rod B individually with SM-1 high burnup elements replaced by SM-1 Core II elements;

   c. Rod A and rod B individually with SM-1 high burnup and SM-2 low burnup elements replaced by SM-1 Core II elements.

5. An additional test method is recommended for calibrating the five rod bank. The test would consist of calibrating each of the bank rods in the vicinity of the bank position and adding the five worths obtained. This would allow possible greater accuracy since each individual rod would be moved 1/2 in. or so at a time instead of moving all five rods 0.1 in. or so simultaneously. Performing this test with rods A and B at 19.00 in. would render inter-rod effects negligible.

6. Gross fission product iodine level should be monitored daily. The ion exchange-gamma spectrometer method is preferred since it is simpler and appears to be more accurate than the radiochemical - G-M tube method, due to the possibility of errors in different chemists' techniques when using the latter. Measurement of gross fission product iodine levels provides a single and adequate method for detecting gross changes of element leakage so that corrective action may be taken, if required.

7.0 REFERENCES

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