ACNP-67521

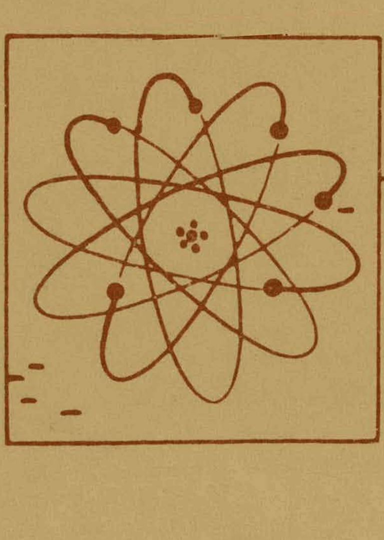
PATHFINDER ATOMIC POWER PLANT

XENON REACTIVITY TEST (335)

Submitted to
U. S. ATOMIC ENERGY COMMISSION
NORTHERN STATES POWER COMPANY
and
CENTRAL UTILITIES ATOMIC POWER ASSOCIATES

by

ALLIS-CHALMERS MANUFACTURING COMPANY
ATOMIC ENERGY DIVISION
Bethesda, Maryland



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Ref: AEC Contract No. AT(11-1)-589

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by P. S. Lacy and T. M. Raby

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NORTHERN STATES POWER COMPANY
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by
ALLIS-CHALMERS MANUFACTURING COMPANY
under
Agreement dated 2nd Day of May 1957, as Amended
between
Allis-Chalmers Manufacturing Company and Northern States Power Company
under
AEC Contract No. AT(11-1)-589

June 1967

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Approved:	Approved:
R. W. Klecker Project Manager Pathfinder Project	D. F. McElroy Vice President Engineering
Allis-Chalmers Manufacturing Company Atomic Energy Division Bethesda, Md. 20014	Northern States Power Company 414 Nicollet Avenue Minneapolis, Minnesota 55401

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FOREWORD

One of a series of reports on research and development in connection with the design of the Pathfinder Atomic Power Plant, this particular report describes xenon-samarium poisoning reactivity measurements (Test 335) carried out during the rise-to-power phase of the reactor startup. The Pathfinder plant is located at a site near Sioux Falls, South Dakota; it reached initial criticality early in 1964 and attained approximately 85% of the design power objective of 190 Mwt in early 1967. Northern States Power is the owner and operator of the plant. Allis-Chalmers is responsible for the design and construction of the plant and for performance of research and development projects.

The U.S. Atomic Energy Commission, through Contract No. AT(11-1)-589 with Northern States Power Company and Central Utilities Atomic Power Associates (CUAPA), are sponsors of the research and development program. The plant's reactor is of the Controlled Recirculation Boiling Water type with nuclear superheat.

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TABLES

FIGURES

1. INTRODUCTION

This report contains the results of xenon poisoning reactivity measurements (Test 335) carried out as part of the initial startup and testing of Pathfinder plant, which included a programmed gradual increase of reactor power to the full design power objective of 190 Mwt. The objective of the xenon tests was to determine the reactivity associated with xenon at intermediate and full power levels. The reactivity associated with samarium buildup was also determined. However, power escalation was limited to 88 percent of the projected full power of 190 Mwt. The test results are used to verify analytical calculation methods, to derive control rod calibration data, and to determine the capability of the reactor to startup after shutdown. Xenon measurements were conducted as part of startup test procedure 335.*

Initial measurements were made at a reactor power of 76 Mwt, or at approximately 40 percent of full power. The measurements were repeated with slightly reduced scope at reactor powers of 114 Mwt and 153 Mwt, or 60 and 80 percent, respectively, of full power. Additional measurements were then taken at the maximum achieved power level, which was 162 Mwt.

*Test Procedure No. 335, "Pathfinder Atomic Power Plant Xenon Radioactivity," Rev. 1, dated June 3, 1966; Allis-Chalmers Atomic Energy Division.

2. GENERAL TEST METHOD

Xenon buildup to equilibrium conditions at several reactor power levels was measured by following the movement of a calibrated control rod group. Xenon buildup to peak and subsequent decay after shutdown from power was similarly measured. The detailed procedure is presented as part of Test Procedure 335, "Pathfinder Atomic Power Plant Xenon Reactivity," (Rev. 1, dated June 3, 1966). The reactor was brought to the desired power under normal operating conditions. The power level was then held constant at steady-state conditions until equilibrium xenon concentration in the core was reached. The positions of the control rods and other operating data were recorded as the xenon approached equilibrium.

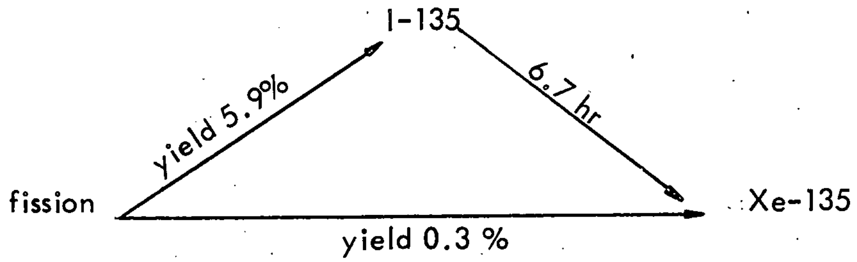
After xenon reactivity approached its equilibrium value, the reactor was shut down and immediately brought critical again at low power. Reactor water temperature was maintained near the reference operating temperature. The reactivity worth of xenon buildup to maximum, and the subsequent decay to low concentrations, was determined by periodic measurement of the critical position of the calibrated rod bank; this bank is in control at low power during the xenon transient.

3. APPLICABLE THEORY AND ANALYTICAL CALCULATIONS

The most important fission product in the reactor is Xe-135 because of its exceptionally large absorption cross section for thermal neutrons ($\sim 2.7 \times 10^6$ barns). The presence of Xe-135, therefore, has a significant effect on core reactivity. The main proportion of Xe-135 is produced from the precursor I-135 by beta decay:

$$\text{Te-135} \xrightarrow{\sim 1\ \text{min}} \text{I-135} \xrightarrow{6.7\ \text{hr}} \text{Xe-135} \xrightarrow{9.2\ \text{hr}} \text{Cs-135} \xrightarrow{2 \times 10^6\ \text{yr}} \text{Ba-135 stable}$$

From the above, because of the short half-life of Te-135, it may be assumed that I-135 is formed directly by the fission process. The fission decay chain in which Xe-135 is formed is:



The differential equations describing the rate of change of xenon concentration for a point reactor system are given below:

$$\frac{dN^{I-135}}{dt} = \Sigma_f \phi \, \gamma^{I-135} - N^{I-135} \lambda^{I-135}, \text{ and}$$

$$\frac{dN^{Xe-135}}{dt} = \Sigma_f \phi \, \gamma^{Xe-135} + N^{I-135} \lambda^{I-135} - N^{Xe-135} (\sigma_a^{Xe-135} \phi + \lambda^{Xe-135})$$

where

$\Sigma_f \phi$ = reactor fission rate (fissions/cm^3 sec)

γ^{I-135} = fission product yield of I-135 (atoms/fission) = 0.061

λ^{I-135} = decay rate of I-135 (l/sec)

γ^{Xe-135} = fission product yield of Xe-135 (atoms/fission) = 0.003

λ^{Xe-135} = decay rate of Xe-135 (l/sec)

N^{I-135} = concentration of I-135 (atoms/cm^3)

N^{Xe-135} = concentration of Xe-135 (atoms/cm^3)

σ_a^{Xe-135} = microscopic absorption cross section of Xe-135 (barns)

A brief review of these equations shows that the equilibrium concentration of Xe is generally dependent on the reactor flux. However, for flux levels above 10^{14} neutrons/cm^2 sec, it remains essentially constant.

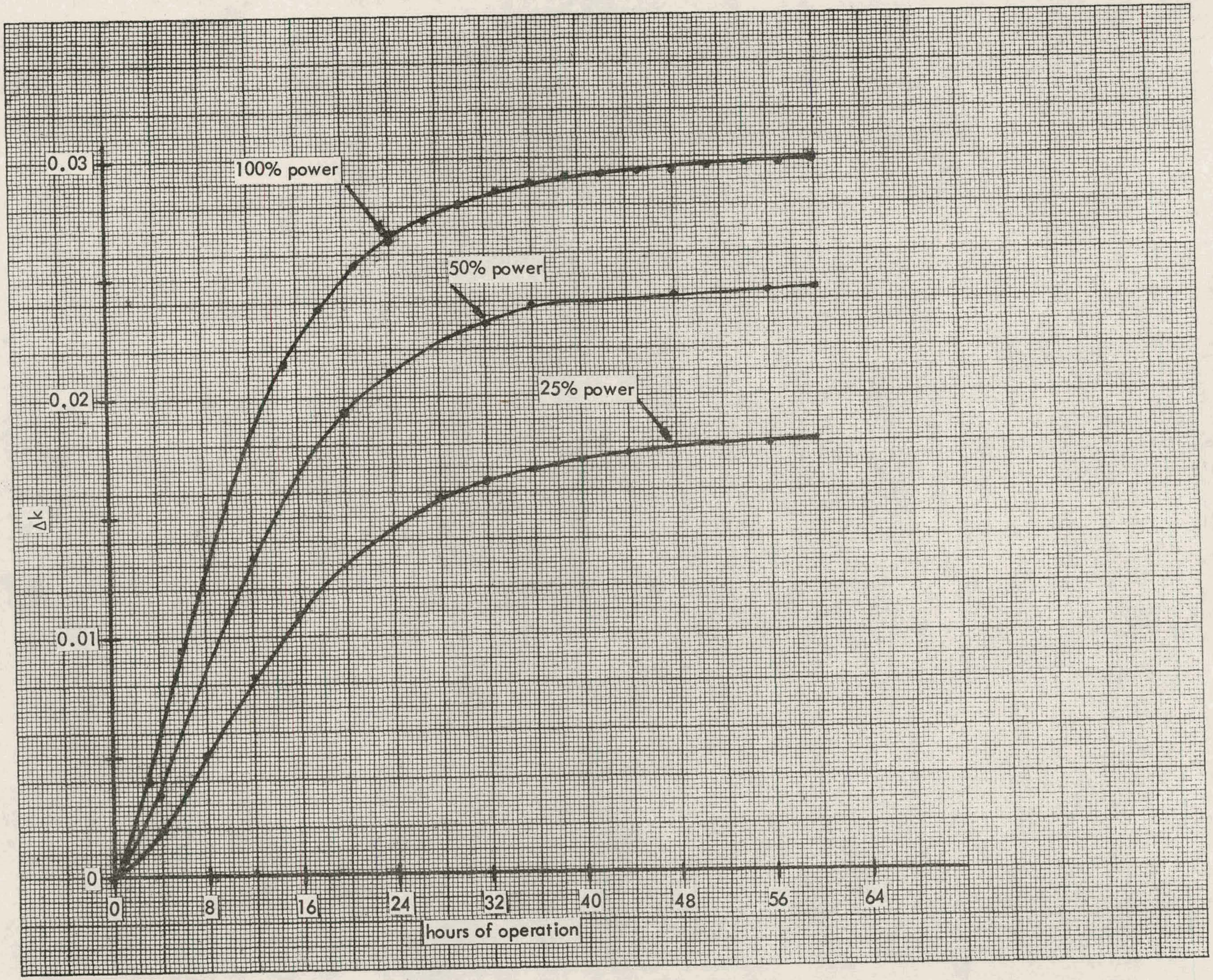
Another important fission product that affects core reactivity because of its relatively high cross section for thermal neutrons is Sm-149. This is a stable isotope and the end product of the decay chain:

Nd-149 $\xrightarrow{1.8 \text{ hr}}$ Pm-149 $\xrightarrow{53 \text{ hr}}$ Sm-149 which occurs in about 1.4 percent of fissions. Because Sm-149 is not radioactive, equilibrium concentration during reactor operation is independent of the neutron flux and reaches a limiting equilibrium value.

Of primary concern in reactor operations is the amount of reactivity controlled by the equilibrium xenon poison at different power levels and the rate of change of poison after reactor shutdown. After about 40 to 60 hr of continuous operation at constant power, the xenon concentration will reach an equilibrium value. Production by direct fission and by decay of I-135 will be balanced by neutron absorption and by radioactive decay. The reactivity effect of xenon poison buildup to equilibrium was calculated for three different power levels. The results are shown in Fig. 3.1 for power levels of 25, 50, and 100 percent of the full design power, which is 190 Mwt. At full power the reactivity lost due to equilibrium xenon was calculated to be 3 percent Δ k.

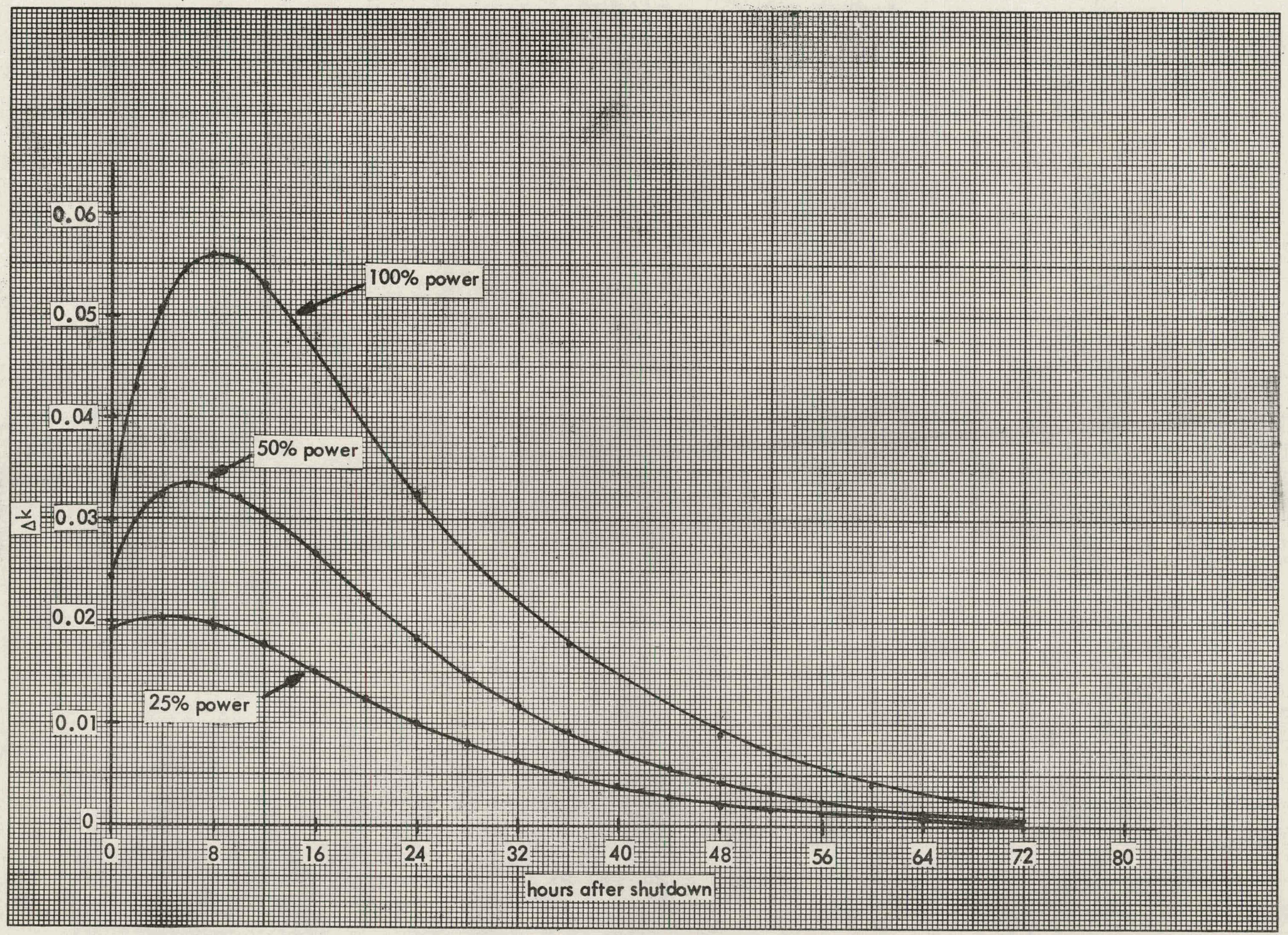
Immediately after shutdown from power, xenon concentration in the core begins to increase. This increase occurs because I-135 has a shorter half-life than Xe-135. At shutdown, I-135 forms Xe-135 by radioactive decay at a rate much faster than the rate of decay of Xe-135, almost none of which is now being lost by burnup due to neutron capture. Therefore, the concentration of xenon after shutdown will increase and will reach a peak after approximately 6 to 8 hr. At peak xenon concentration, the production of Xe-135 by I-135 decay exactly matches Xe-135 decay to Cs-135. After reaching peak concentrations, the xenon concentration will start to decrease, since the buildup of Xe-135 by I-135 is less than its radioactive decay because of the fact that no more I-135 is being produced. Figure 3.2 shows the reactivity worth of xenon poison as a function of time after shutdown for power levels of 25, 50, and 100 percent of full design power. Peak xenon worth was calculated to be 5.61 percent Δ k, and it occurs approximately 8 hr after shutdown from full power operation at equilibrium conditions.

Calculations also indicate that the absolute worth of both equilibrium and transient xenon is only slightly dependent on the control rod configuration. This was determined using successive two-dimensional (RZ) diffusion calculation for the Pathfinder core.



XENON BUILDUP AT POWER

FIG. 3.1



XENON TRANSIENT AFTER SHUTDOWN

FIG. 3.2

4. XENON REACTIVITY AT 76 MWT, OR 40 PERCENT OF FULL POWER

A programmed reactor power increase to 76 Mwt, or 40 percent of full power, was initiated on August 5, 1966 and was completed at 0700 on August 18, 1966. The reactor had been operating at a constant power of 76 Mwt with equilibrium xenon concentration in the core for 9 hr prior to shutdown. The rod configuration during this period was that for normal startup (Groups III, IV and V at 73 in.; Group II fully in; and Group I controlling). Group I reached 73 in. at 0700 on August 18, at which time the reactor was shut down. The reactor was then returned to critical at 0924 on August 18 with Groups I and II fully in, Group III controlling, and Groups IV and V at 73 in. The reactor water was held at 450 ± 5 F; criticality was maintained until 1400 on August 20. Group III was controlling during this period of approximately 55 hr, and Group III differential worths were measured for approximately every inch of rod motion. The Group III heights during this xenon transient are plotted on Fig. 4.1. All heights are corrected to 450 F. The points at 0 and 60 hr are extrapolated from the data. A point is also plotted at 0 hr for equilibrium xenon at 478 F.

Using period data taken during the xenon transient test, a Group III differential worth curve was constructed as shown on Fig. 4.2. The dashed curve above 58 in. is estimated. The integral of this curve is also shown on Fig. 4.2.

Calculations were done to exactly match the power history just prior to the reactor shutdown from 76 Mwt for performance of the xenon test. The calculated worth of xenon is shown on Fig. 4.3. Also on Fig. 4.3 the measured worth of xenon is shown. To obtain the measured curve, the reactivity worth between the Group III heights shown on Fig. 4.1 and the xenon free position was determined using the integral worth on Fig. 4.2. The xenon-free position was determined by correcting the extrapolated Group III height at 60 hr shown on Fig. 4.1, using a calculated xenon worth of 0.144 percent Δ k at 60 hr. The xenon-free Group III height is 31.3 in. at 450 F.

Since the calculated and measured xenon worth curves are in good agreement from 3 to 60 hr, the calculated worth was taken to be the measured value at shutdown. This assumption gives a Group III height of 50 in. at shutdown for conditions of zero power and 450 F. As can be seen on Fig. 4.1, this point fits the measured data well. It is also the same height that Group III had at 17.8 hr after shutdown. This time agrees well with calculations which predicted that the xenon worth at 17 hr after shutdown would be the same as its worth at shutdown. This point in time is called the xenon return time.

Table 4-1 summarizes calculated and measured results of this test. The first column of calculated numbers is for conditions which simulate this test. The third column presents the results of calculations done for the reactor at equilibrium xenon at 76 Mwt.

TABLE 4-1

XENON TRANSIENT AT 76 MWT TEST SUMMARY

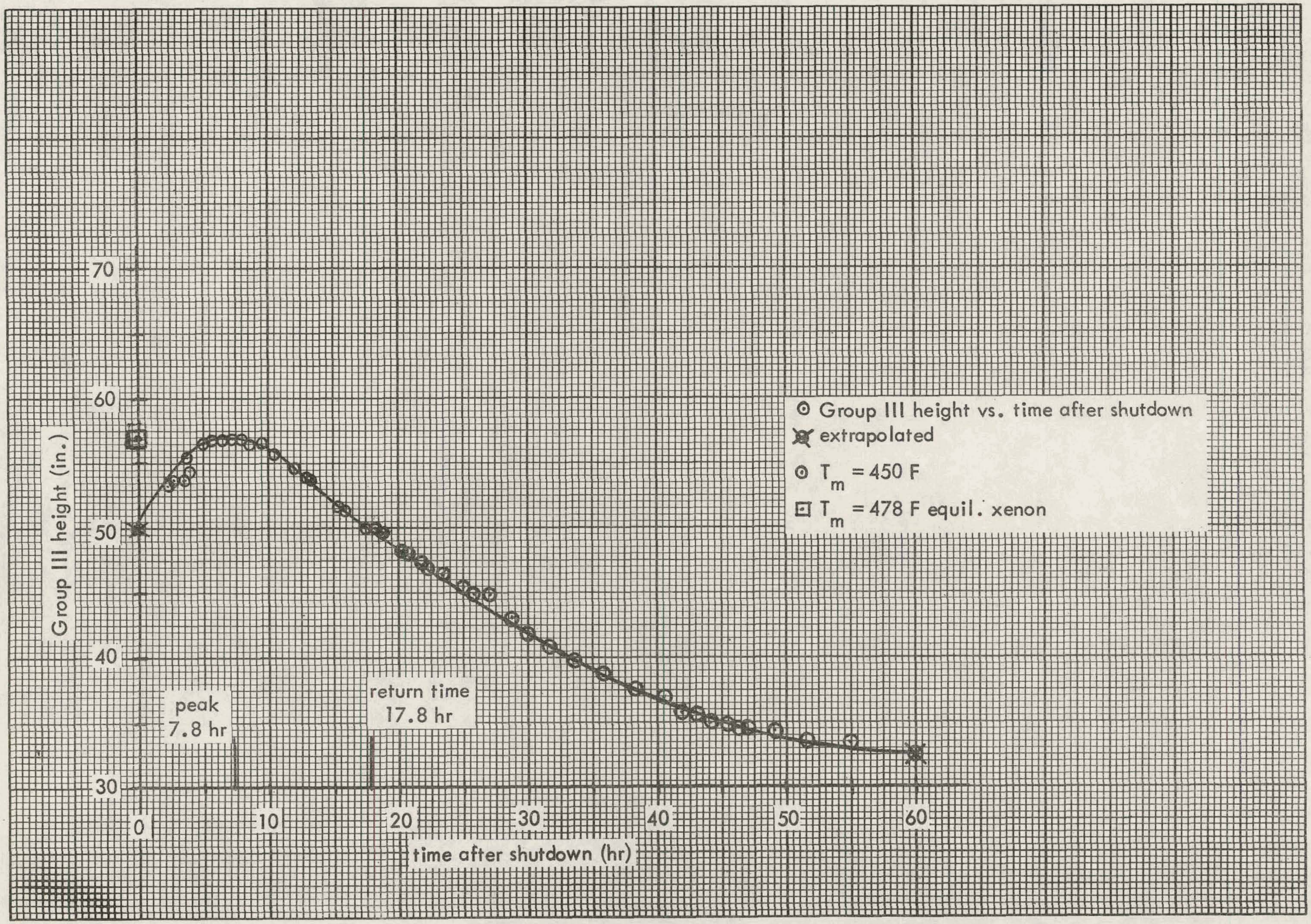
Xenon Worth (% Δ k)

	Calculated	Measured	Calculated for Equil. at 76 Mwt
Worth at shutdown	2.03	2.03	2.28
Maximum worth	2.70	2.75	3.10
Time of maximum worth	7.0 hr	7.8 hr	
Return time	17.0 hr	17.8 hr	

Calculated results in Table 4-1 also show that the worth of Group II control rod from zero to 14 in. is 0.25 percent Δ k, since at equilibrium xenon for 76 Mwt the Group II position is 14 in.

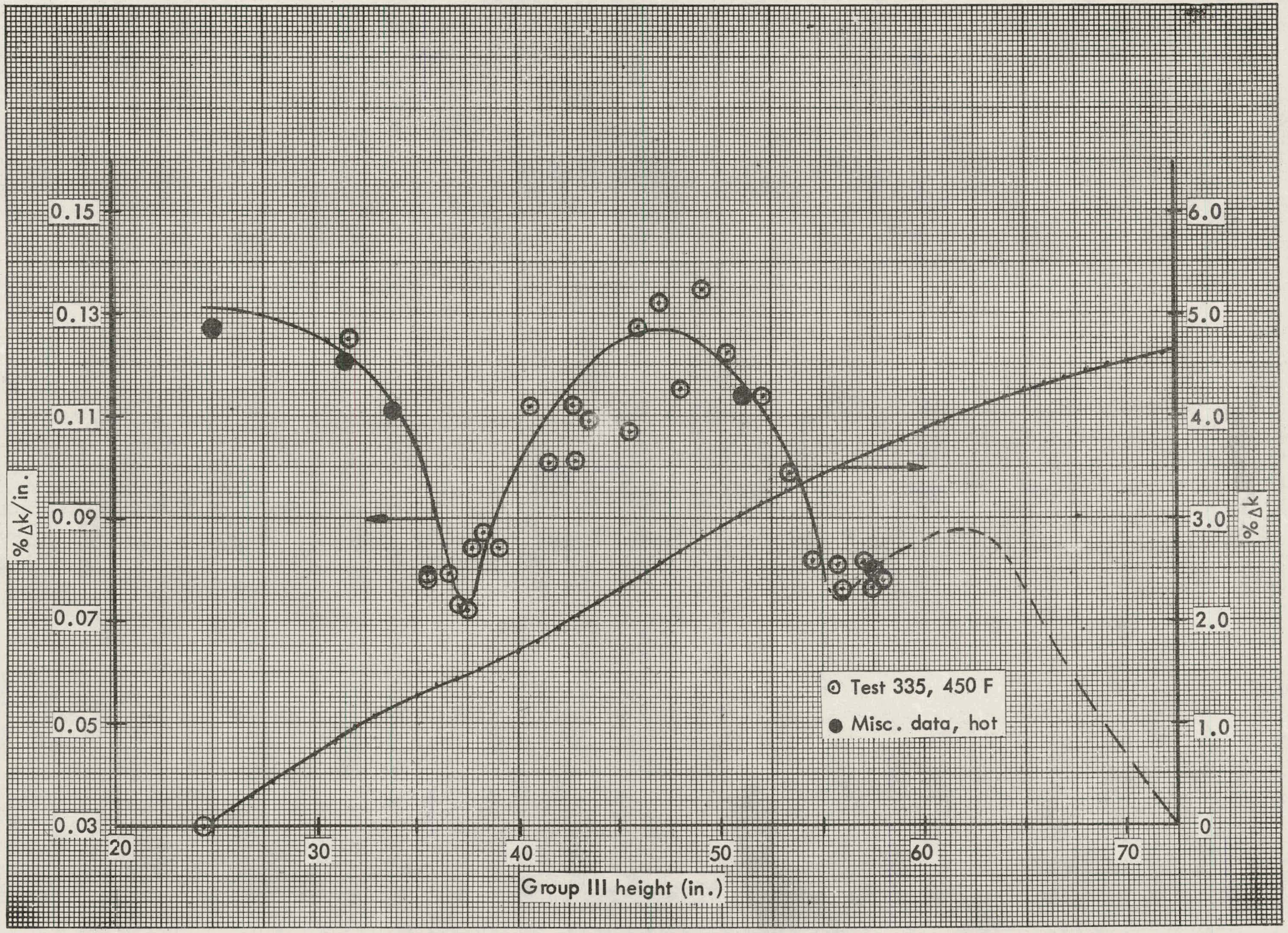
As an additional check on the xenon calculations and on the Group III rod worth shown on Fig. 4.2, calculations were done to follow a measured xenon buildup for 28 hr at 40 Mwt. These calculations predict a xenon worth of 1.56 percent. This compares well with a Group III worth of 1.60 percent Δ k for movement from 42.0 to 56.2 in.

In summary, the xenon-free Group III height at 450 F is estimated to be 31.3 in. A clean core Group III height at 450 F is estimated to be 28.0 in. This estimate uses a 420 F clean core Group III height of 24.5 in. and a temperature coefficient of -1.55×10^{-4} Δ k/°F. The worth of Group III from 28.0 to 31.3 in. is 0.41 percent Δ k. The calculated worths of samarium at shutdown and at 60 hr are 0.31 percent Δ k and 0.34 Δ k. Thus, 0.07 percent Δ k is attributed to fuel burnup and long term fission product burnup. At this time the fuel exposure in the boiler core is estimated to be 762 Mwd.



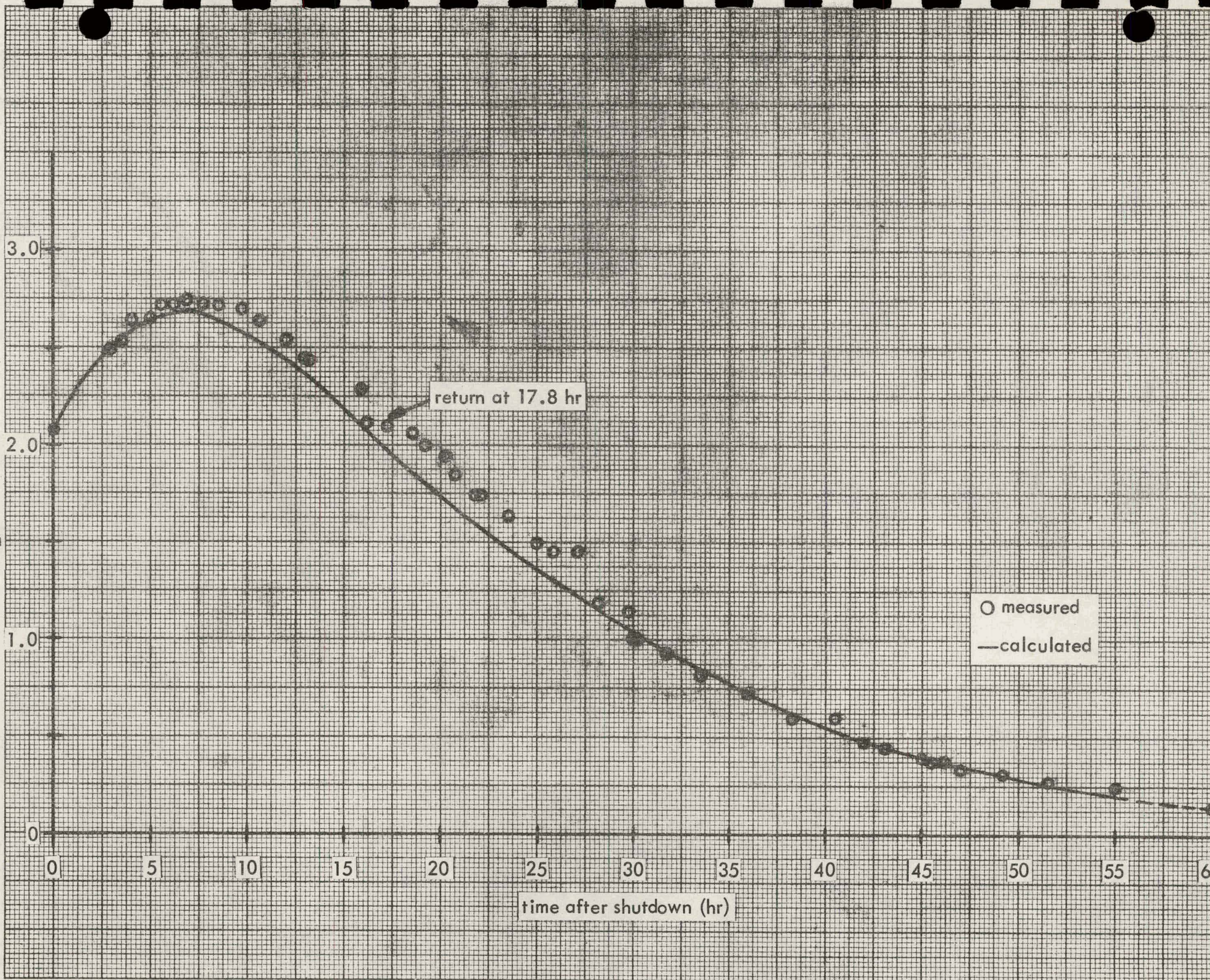
PATHFINDER I TEST 335, 40 PERCENT POWER

FIG. 4.1



PATHFINDER I GROUP III WORTH

FIG. 4.2



PATHFINDER I TEST 335, 40 PERCENT POWER; XENON REACTIVITY FOLLOWING SHUTDOWN

FIG. 4.3

5. XENON REACTIVITY AT 114 MWT, OR 60 PERCENT OF FULL POWER

Reactor power increase to 114 Mwt, or to 60 percent of full power, was initiated on December 1, 1966 from the 40 percent power level. Starting at 1000 hr on December 3, 1966, the core power level was held approximately constant for 31 hr to achieve equilibrium xenon. The core was shut down at 1700 hr on December 4, 1966, and the xenon transient followed at zero power. The core power history prior to this shutdown is summarized in Table 5-1.

TABLE 5-1

EQUILIBRIUM XENON BUILDUP

Date and Time		Power (Mwt)	Group II Height (in.)
December 3:	1000	109.1	27.5
	2340	114.6	33.0
December 4:	0300	114	34.0
	0700	114	35.0
	1100	114	36.0
	1600	114	37.0
	1700	114	37.0

The xenon transient test was done after a shutdown from 60 percent power. The Control Rod Group III rod heights after shutdown from 60 percent power are plotted on Fig. 5.1. Period data taken during the test provide Group III differential worth as a function of group height.

This data, with data taken during the xenon transient following a shutdown from 40 percent power, provides a Group III differential worth curve for the upper half of the core. A composite Group III worth curve is shown in Fig. 5.2.

Using this curve, the reactivity worth of 60 percent power xenon was computed in the same manner as for 40 percent power, as described in Sec. 4. These results are listed in Table 5-2. Also listed in Table 5-2 are calculated results based on simulation of this test for equilibrium conditions at 114 Mwt.

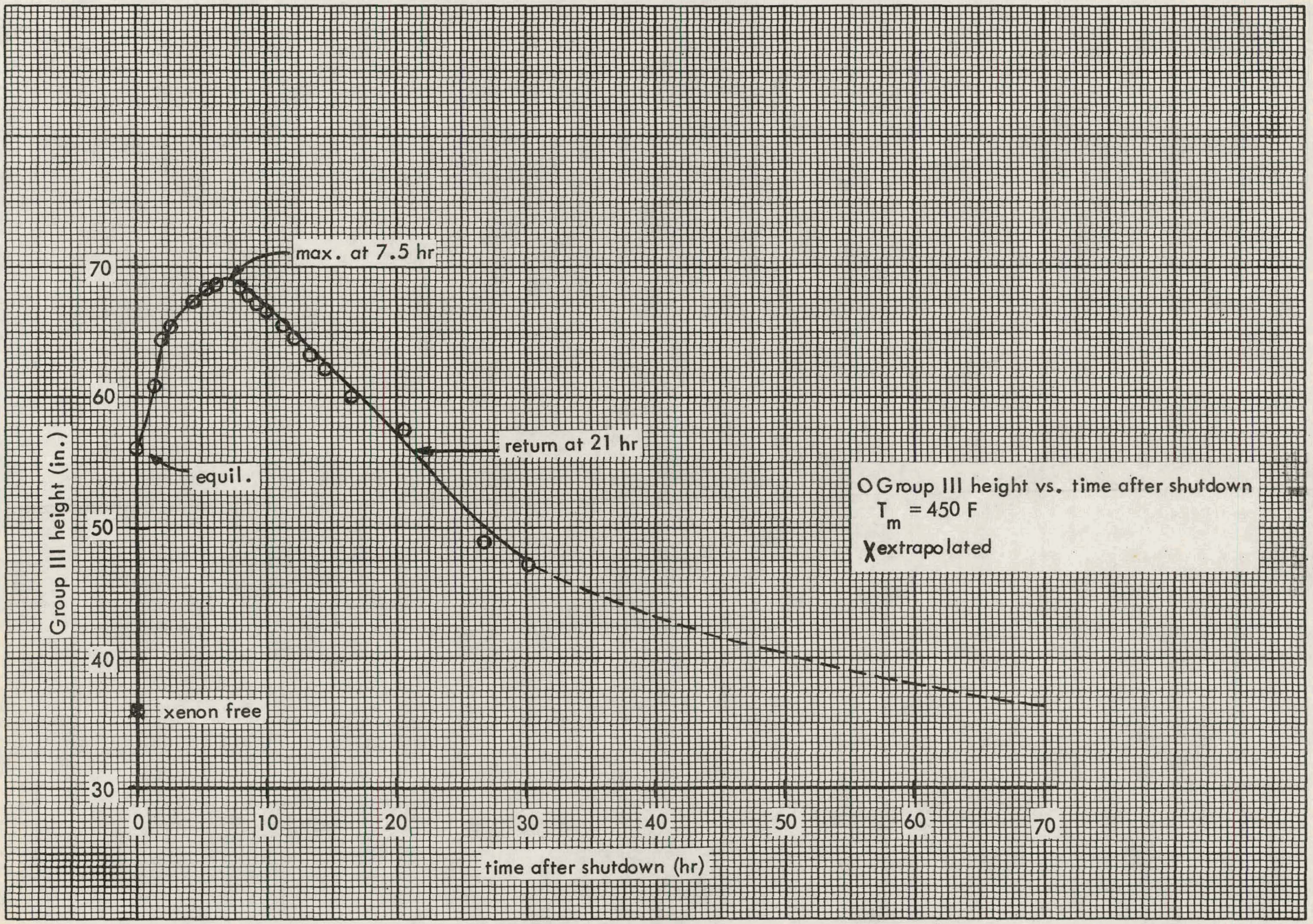
TABLE 5-2

XENON TRANSIENT AT 114 MWT TEST SUMMARY

	Xenon Worth (% Δ k)		
	Calculated	Measured	Calculated for Equil. at 114 Mwt
Worth at shutdown	2.55	2.10	2.65
Maximum worth	3.85	3.10	4.00

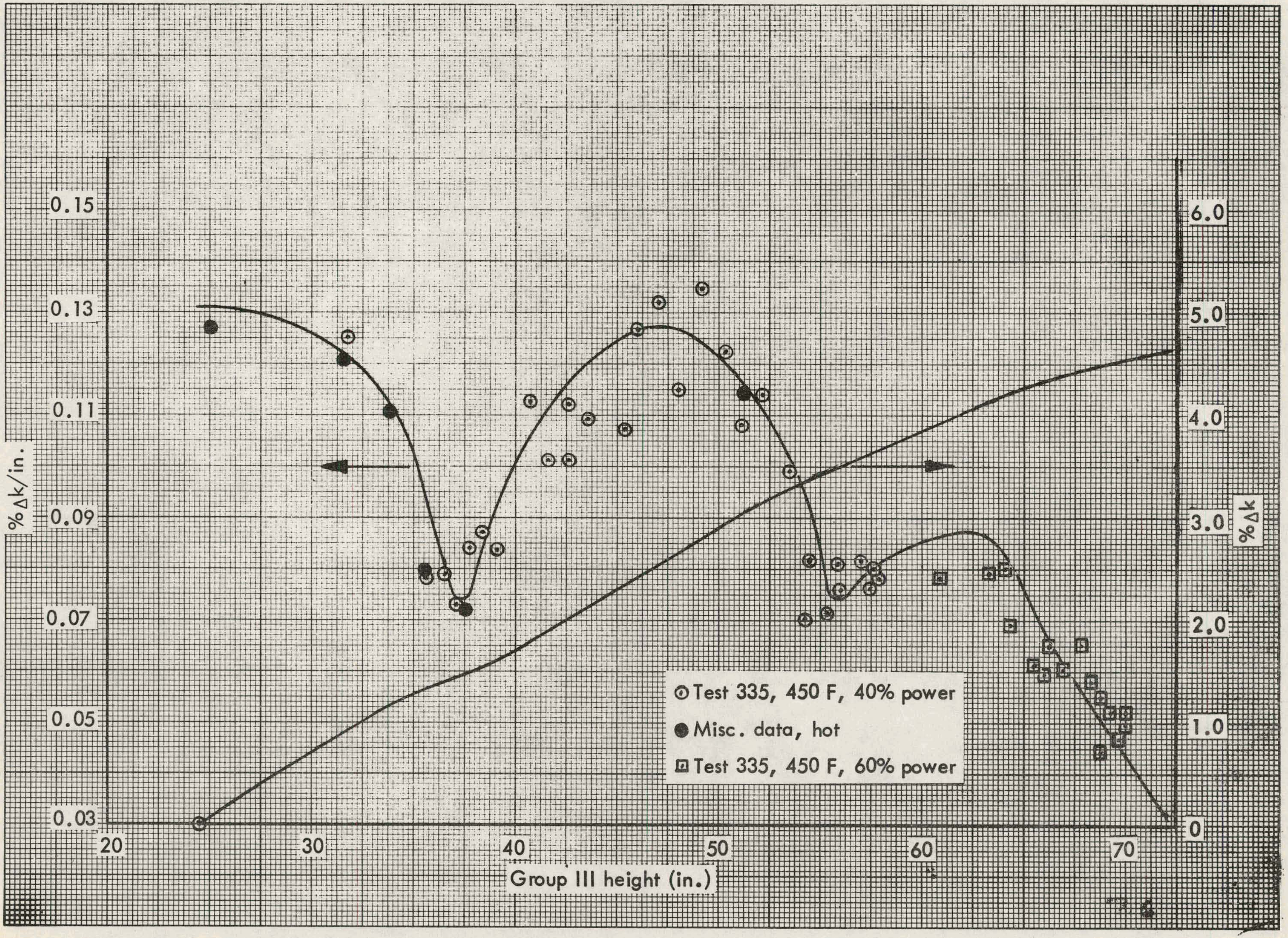
Unlike the findings at 40 percent power, where agreement was very good, the measured values are low relative to the calculated values. The calculations listed in Table 5-2 and those performed at 40 percent power are results of an analysis in which the reactor is treated as a one-point reactor. For this analysis, equilibrium xenon is worth 3.0 percent Δ k at full power and with all rods out. For other than full power conditions, the xenon worth relative to the worth at full power is directly proportional to the ratio of the xenon inventories existing at the actual conditions and at full power, based on the one-point model.

Two-dimensional RZ calculations were done simulating the 60 percent power conditions. The worth of xenon was computed for the operating core at 60 percent power and for the zero power core with the 60 percent power xenon inventory. The control rods were at near-critical positions. These calculations yielded xenon worths of 2.04 and 2.57 percent Δ k for zero power and for 60 percent power core respectively. Because of these results, it appears that the one-point model is less valid at the higher power levels, and hence at higher voids in the core.



PATHFINDER I TEST 335, 60 PERCENT POWER

FIG. 5.1



PATHFINDER I GROUP III WORTH

FIG. 5.2

6. XENON MEASUREMENTS AT 153 MWT, OR 80 PERCENT OF FULL POWER

Xenon reactivity measurements were not scheduled for 80 percent of power; however, on December 25, 1966 at 1500 a scram occurred from 153 Mwt. Group II rods were at 48.8 in. Zero power criticality was achieved at 2100 with Group II at 14.4 in. and with the moderator temperature at 462 F. This permitted another test and evaluation of xenon transient reactivity after shutdown from 80 percent of full power.

Test results indicate a peak xenon reactivity value of 3.90 percent Δk. This measurement is based on zero power, 450 F, rod position of Group III at 37.3 in. for the xenon-free condition and Group II at 0 in. for the 6-hr xenon condition. Calculations using the one-point model gave a xenon reactivity worth of 4.80 percent Δk 6 hr after shutdown from 80 percent of power. Thus, like the measurements at 60 percent of power, the one-point model overestimates peak xenon worth by about 25 percent for the hot zero power standby condition. However, these same methods worked very well at 76 Mwt, or 40 percent of power, where the voids were low and where less difference existed in control rod worth between the zero power and power conditions.

7. XENON MEASUREMENTS AT 162 MWT, OR 85 PERCENT OF POWER

Additional xenon reactivity measurements were performed at a reactor power level of 162 Mwt (85 percent of power). This power was reached at 1300 February 23, 1967; and it was held constant until equilibrium conditions were attained. Control Rod Group II was controlling and reached 68.5 in. withdrawal at the time of reactor shutdown. Group II had moved less than 0.5 in. in the 4 hr preceding the shutdown. Control Rod Groups I, III, IV, and V were at 73 in. Normal reactor shutdown was begun at 0000 on February 25, 1967. Reactor shutdown was completed in approximately 1 hr, and the reactor was critical again at zero power 4 hr after shutdown, at which time Control Rod Group II was controlling and all other rods were fully withdrawn. Thereafter the xenon transient was followed initially with Control Rod Group II until full insertion; then with Control Rod Group I until full insertion; and finally with Control Rod Group III to a critical position of 42.5 in., achieved 56.5 hr after shutdown. Critical zero power control rod positions were recorded at frequent intervals during xenon buildup to a peak and subsequent decay. Control rod worth was determined at approximately 2-in. intervals for all three rod groups from period data measured during the xenon transient. Reactor water temperature was held close to 450 F throughout the test.

Figure 7.1 gives control rod group height as a function of xenon concentration in the core. Extrapolation of the Control Rod Group III curve gives a critical position of 40.9 in. for the xenon-free core condition. However, after shutdown to zero power, samarium builds up to greater than its equilibrium value. Calculations predict that the worth of samarium at 60 hr after shutdown for this transient is 0.15 percent Δ k greater than immediately following shutdown. Thus, 0.15 percent Δ k should be added to the xenon worth values obtained from the control rod heights of Fig. 7.1. Figures 7.2, 7.3, and 7.4 give differential and integral worth plots constructed from period data taken during xenon transient for Control Rod Groups I, II, and III, respectively.

From plots of control position vs. time after shutdown and control rod worth vs. position, a reactivity curve of the xenon transient was generated. Figure 7.5 gives the reactivity worth of xenon as a function of time after shutdown from a power level of 162 Mwt. The xenon transient peaked at 4.45 percent Δ k about 9 hr after shutdown. This is corrected to 4.60 percent Δ k, which is approximately 6 percent less than expected. Equilibrium xenon worth was estimated to be 2.40 percent Δ k by extrapolation of test data. This is corrected to 2.55 percent Δ k, which is 10 percent lower than the calculated value of 2.85 percent Δ k. The xenon transient returned to equilibrium value about 25 hr after shutdown; 24-hr return time was expected. Table 7-1 summarizes calculated and measured results of this test.

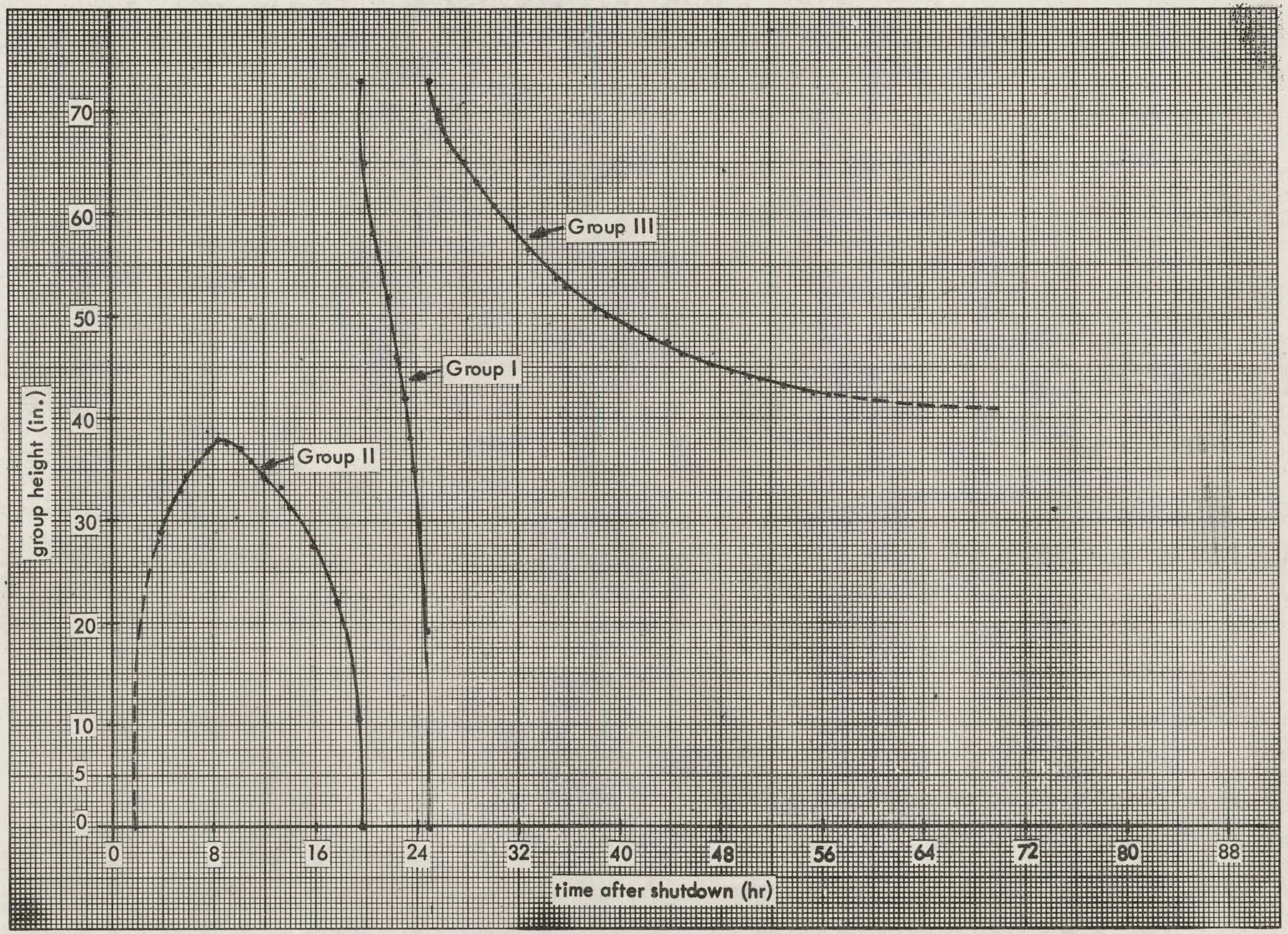
The worth of Control Rod Groups II and III was lower than had been previously measured or estimated. For comparison among calibration data, a composite Group III worth plot showing all hot (450 F) zero power data obtained during the various tests is presented in Fig. 7.6. As can be seen from Fig. 7.6, the Group III data taken during the 85 percent xenon follow yields worths 10 to 20 percent lower than data taken during tests following shutdowns from lower power levels. No valid explanation based on presently developed information could be given for this. Group II data taken during the 85 percent xenon transient also yield worths lower than values inferred from data taken during power operation. These data are changes in power per increment of rod movement, and rod movement required to match xenon buildup during reactor operation with Control Rod Group II control. The explanation for the lower Control Rod Group II worths under zero power conditions is thought to be caused by neutron flux axial distribution effects. At zero power and with no voids, the thermal neutron flux peaks in the upper half of the boiler core. During power operation, voiding in the upper half of the boiler shifts the flux into the lower half, thereby increasing the control rod worth in the lower half of the core. At low power this effect would not be discernable. A quantitative evaluation of redistribution on the axial shape of the Control Rod Group II worth curve as a function of power (or void level) has not been made.

Finally, because of these same differences between measured and calculated values, an RZ PDQ analysis was made at 60 percent power to test the one-point model. This analysis showed that a xenon inventory distribution in a nonvoided heavily-rodded core was worth approximately 85 percent of the reactivity worth of the same xenon in a voided lightly-rodded core. This effect may also provide the explanation for the differences observed in that, here again at 85 percent power, xenon measurements are made for the nonvoided condition; whereas the calculations were realistically made for the voided condition.

TABLE 7-1

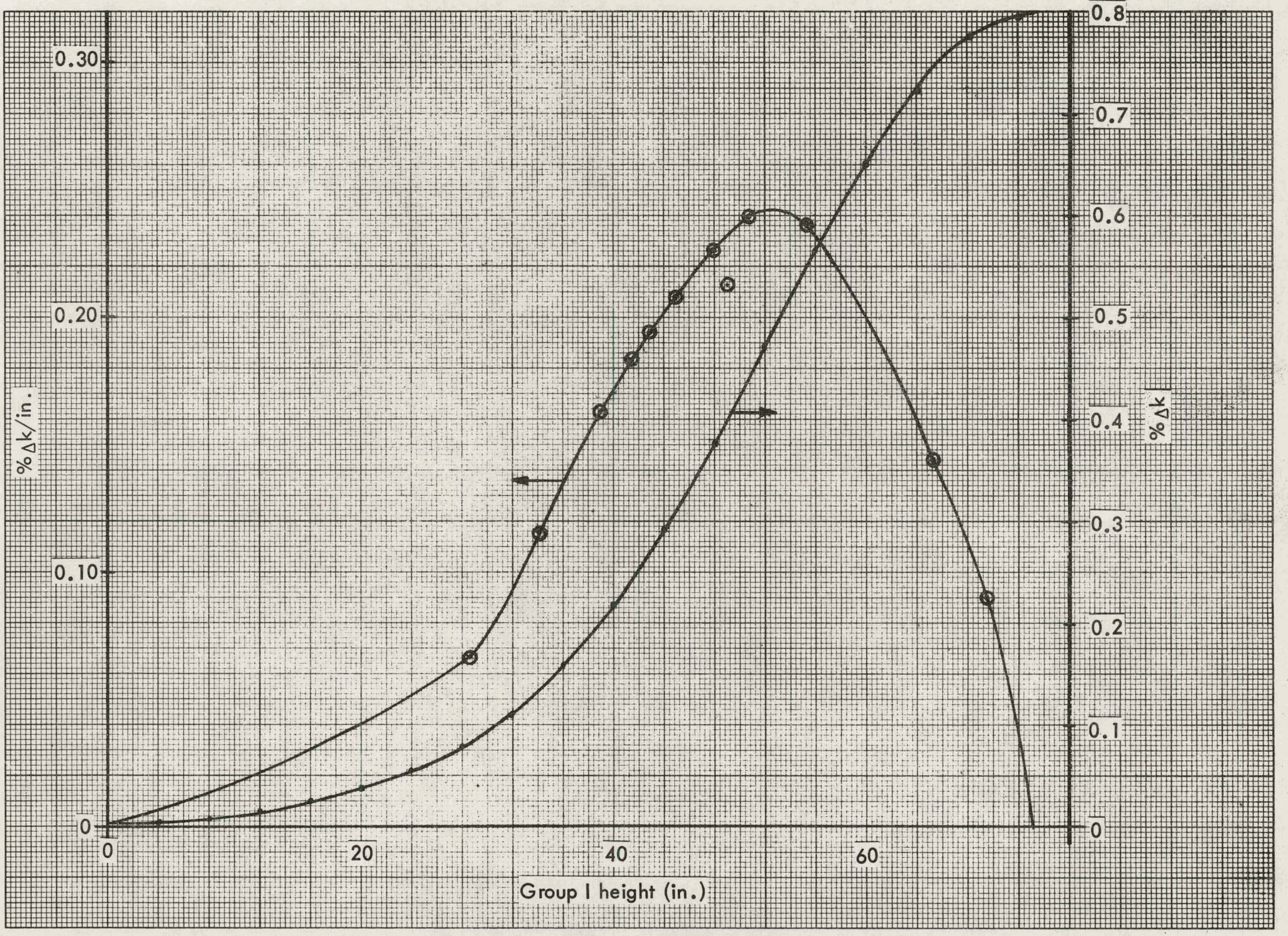
XENON TRANSIENT AT 162 MWT TEST SUMMARY

	Xenon Worth (% Δ k)	
	Calculated	Measured
Worth at shutdown	2.85	2.55
Maximum worth	4.90	4.60
Time of maximum worth	9 hr	9 hr
Return time	24 hr	25 hr

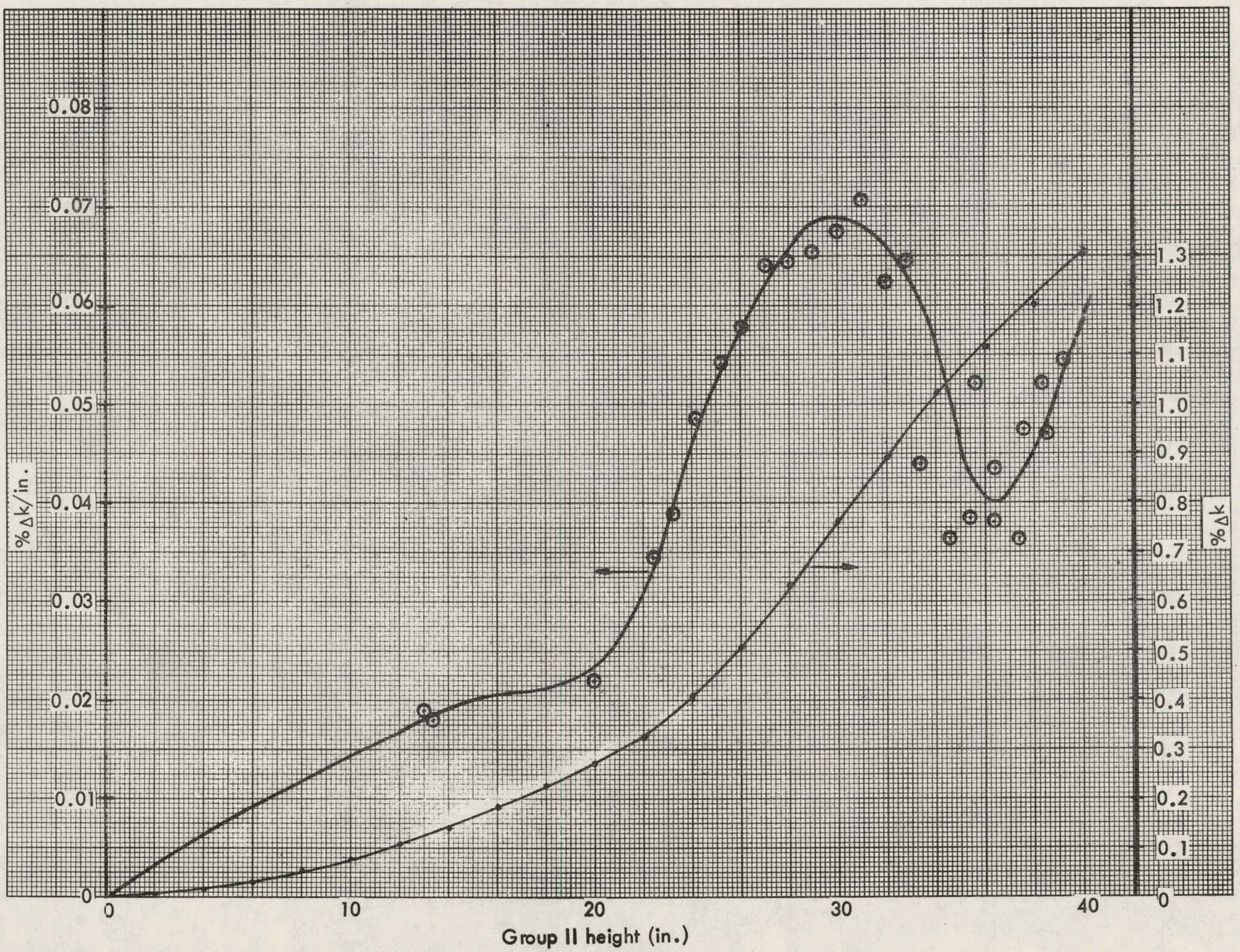


PATHFINDER I ROD GROUP HEIGHT VS. TIME AFTER SHUTDOWN;
TEST 335, 450 F, 85 PERCENT POWER

FIG. 7.1

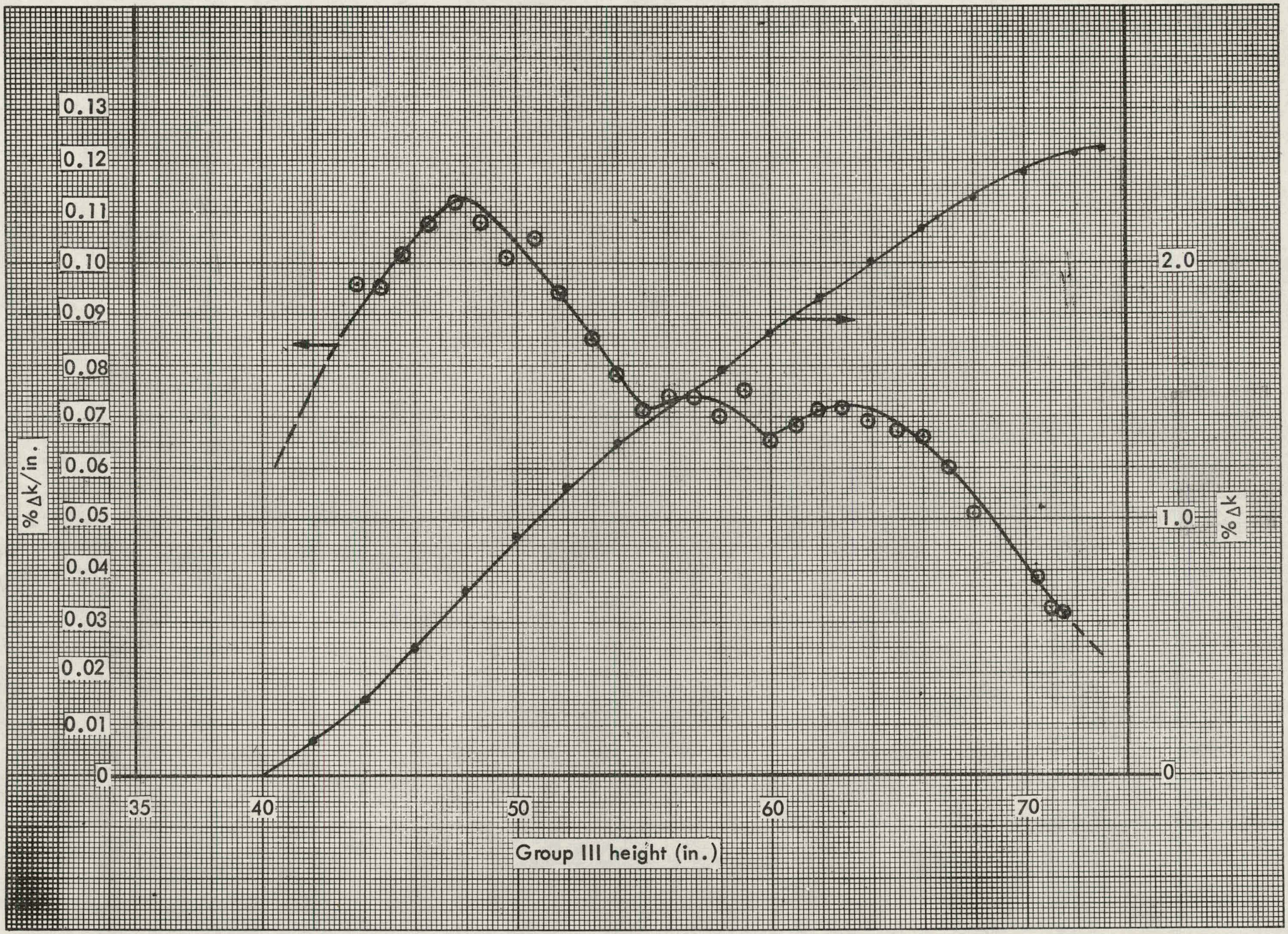


PATHFINDER I GROUP I WORTH; TEST 335, 450 F, 85 PERCENT POWER FIG. 7.2



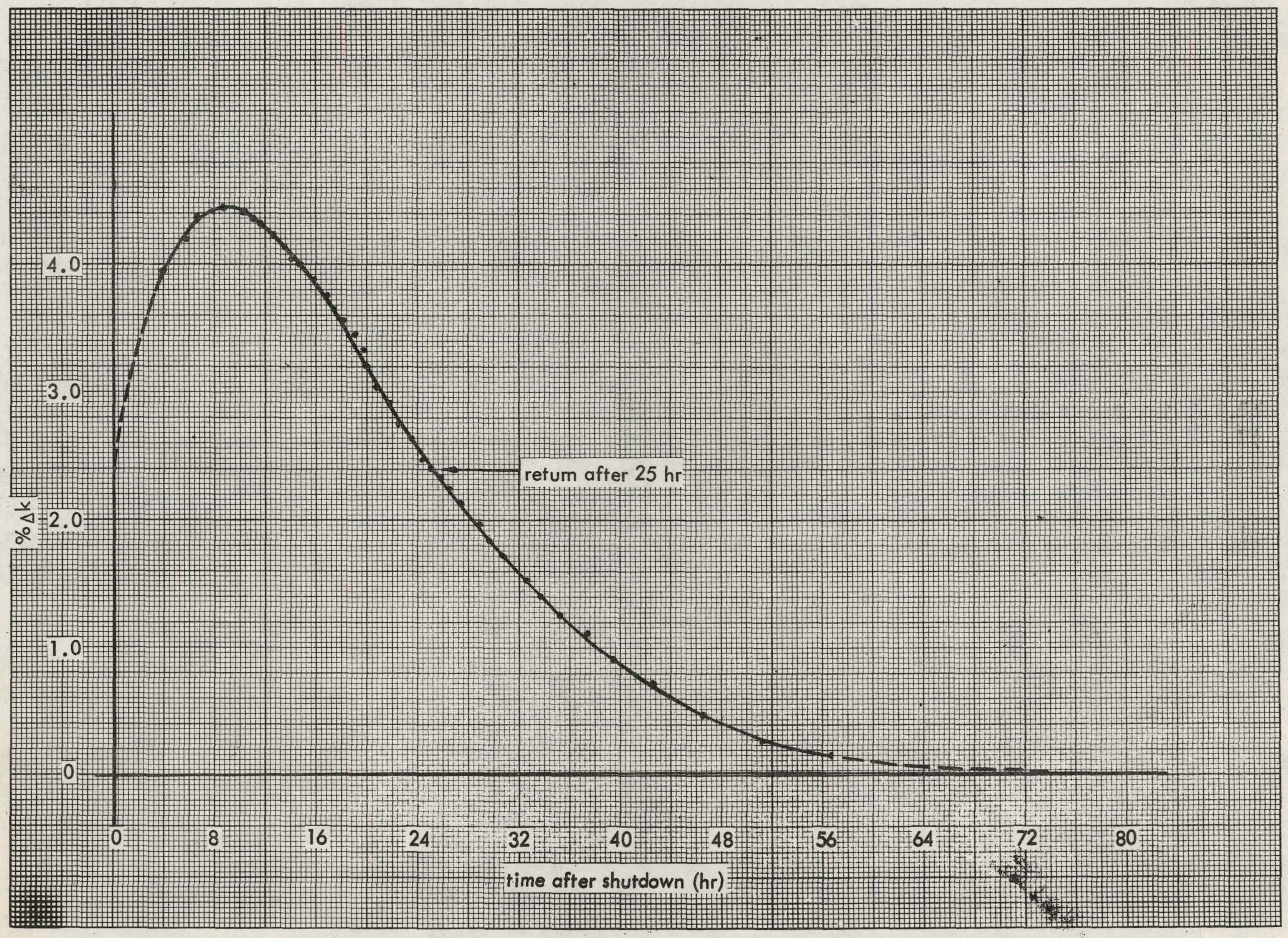
PATHFINDER I GROUP II WORTH; TEST 335, 450 F, 85 PERCENT POWER

FIG. 7.3



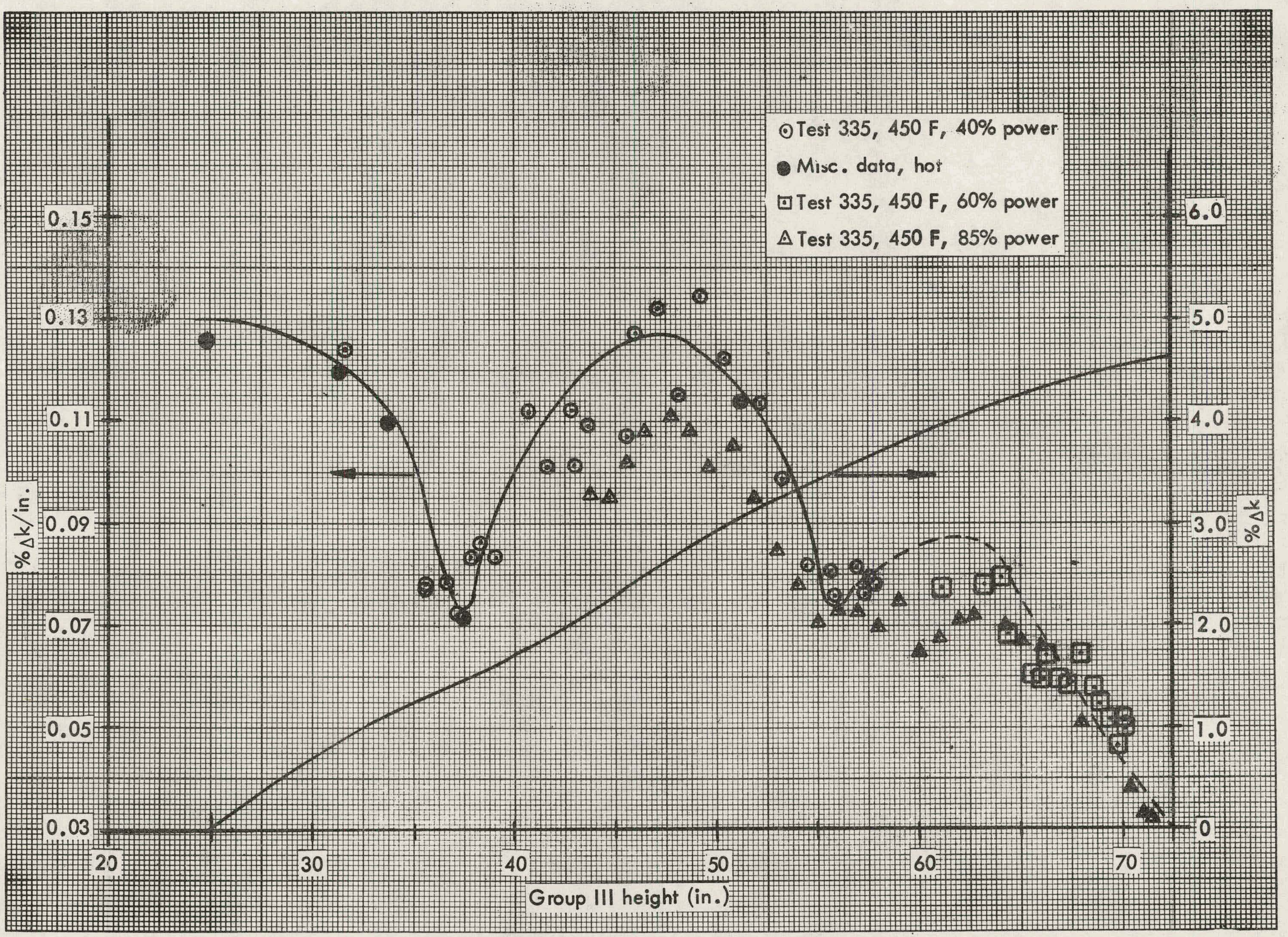
PATHFINDER I GROUP III WORTH; TEST 335, 450 F, 85 PERCENT POWER

FIG. 7.4



PATHFINDER I TEST 335, 85 PERCENT POWER; XENON REACTIVITY FOLLOWING SHUTDOWN

FIG. 7.5



PATHFINDER I GROUP III WORTH

FIG. 7.6

8. EVALUATION OF SAMARIUM WORTH

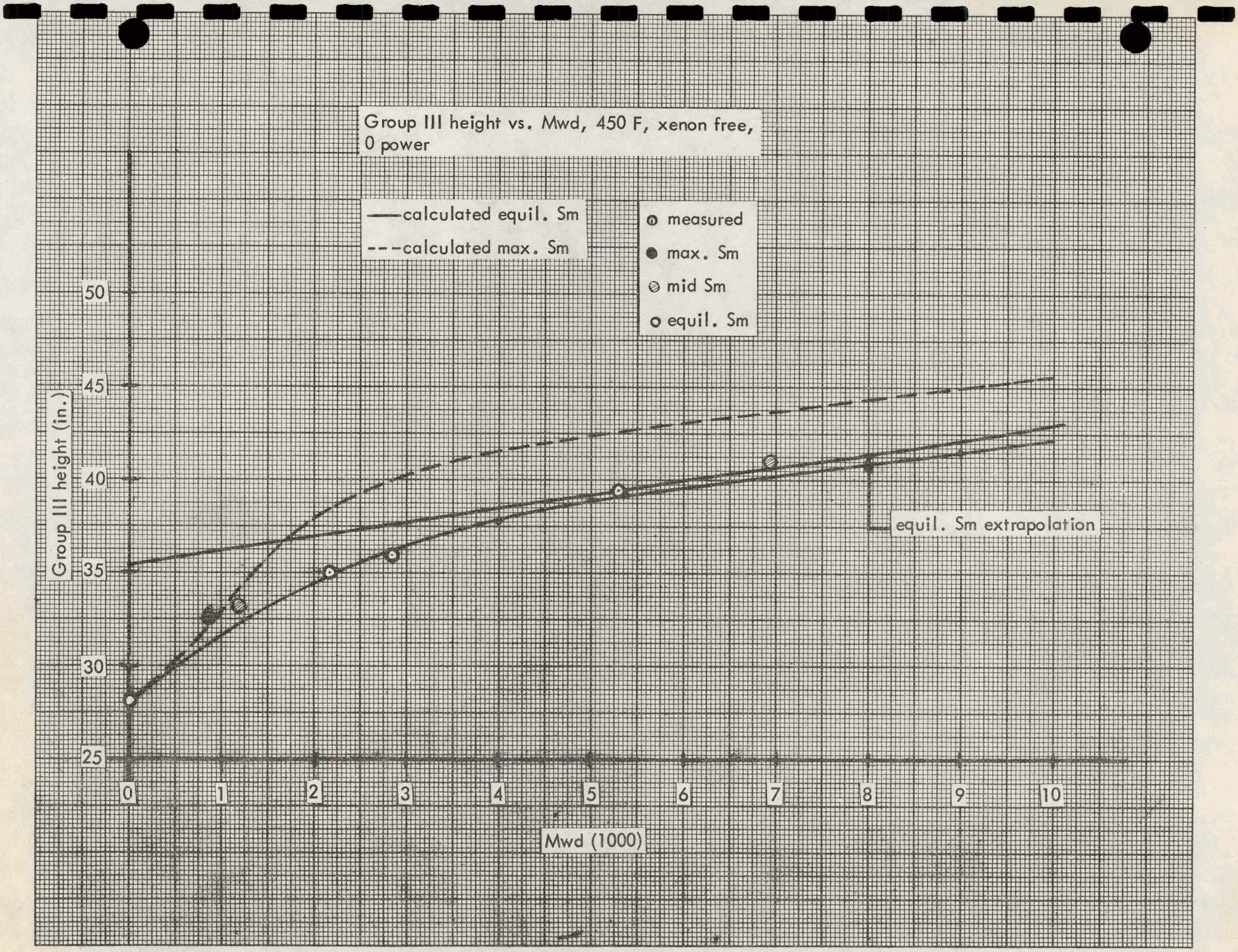
The reactivity worth of equilibrium samarium in Pathfinder was determined using the change in control rod positions as a function of core burnup. The height of Control Rod Group III for criticality at zero power and at approximately 450 F has been determined at the end of each xenon test, as well as at other times following a core shutdown. Group III heights were measured for six approximately xenon-free conditions as a function of core burnup in Mwd. These heights, corrected to 450 F and to the xenon-free condition, are plotted on Fig. 8.1 as a function of Mwd. Control Rod Groups I and II are fully in, and Control Rod Groups IV and V are fully out.

Also shown on Fig. 8.1 are Control Rod Group III heights calculated for equilibrium and maximum samarium as a function of core burnup. These curves use experimental data for the clean core Control Rod Group III height (28.0 in.) at 450 F and experimental data for the Control Rod Group III reactivity worth as a function of group height. Calculated values for reactivity changes due to fuel depletion, long term fission product buildup, and boron-stainless steel shim depletion are then used in conjunction with calculated values of the samarium buildup reactivity worth.

Pathfinder operation for approximately 1500 hr at 50 percent power results in equilibrium samarium. This is approximately 5600 Mwd. Thus, the last two measured points on Fig. 8.1 are at equilibrium samarium. The measured reactivity loss at 7000 Mwd is 1.35 percent Δ k (Control Rod Group III worth from 28.0 to 40.9 in.). The calculated reactivity net loss due to fuel depletion, long-term fission product buildup and B-s.s. shim depletion is 0.50 percent Δ k. The increase in samarium inventory above the equilibrium value for the point measured at 40.9 in. is 0.1 percent Δ k. Thus, equilibrium samarium is determined to be 0.75 percent Δ k. The calculated value is 0.80 percent Δ k.

Consistency between calculated and measured values on Fig. 8.1 can also be seen from a comparison between the line labeled "equil. Sm extrapolation" and the calculated curve of Group III height. The extrapolated line passes through the two measured points and intersects the 0 Mwd axis at 35.3 in. The reactivity worth of Control Rod Group III from 28.0 to 35.3 in. is 0.85 percent Δ k. This difference also represents the reactivity worth of equilibrium samarium.

The reactivity worth of equilibrium samarium in the Pathfinder reactor is thus taken to be 0.80 ± 0.05 percent Δ k.



PATHFINDER I REFERENCE CORE, 40 BORON-STAINLESS STEEL SHIMS

FIG. 8.1

9. SUMMARY

The reactivity effect of xenon concentration in the Pathfinder reactor was measured at various reactor power levels from 40 percent of design power (76 Mwt) up to and including 85 percent of design power (162 Mwt). In general, measured data agreed well with calculations at the lower power levels and were slightly less than expected at the higher power levels. This latter is attributed mainly to the difference between calculations done for a voided unrodded core and measurements done for a nonvoided, rodded core. However, the control rod worth data generated during the test, from which the xenon worth was determined, also introduces a margin of uncertainty. The results indicate that the amount and distribution of voids present in the core have an appreciable effect on the magnitude and shape of the worth measurements. Based on results of measurements at the highest power level reached (162 Mwt), it is estimated that at the full design power of 190 Mwt equilibrium xenon will be worth approximately 2.7 percent Δk, and peak xenon will be worth about 5 percent Δk. This is approximately 10 percent less than the calculated values at full power of 3 percent Δk and 5.6 percent Δk, respectively. However, these extrapolations are based on measurements with a solid water reactor. It seems reasonable to expect that the effect of voids, if factored into the measurements, would yield higher measured values. Thus, it is recommended that the calculated values continue to be used.

Good agreement was achieved between measurements and calculations in determining the worth of equilibrium samarium in the core. In both instances the worth of equilibrium samarium was established as 0.8 percent Δk.