This document was prepared in conjunction with work accomplished under Contract No. AT(07-2)-1 with the U.S. Department of Energy.

UNCLASSIF[redacted]6-1637 RTR-912

DPSP-66-1637

[redacted]

~~his document consists of 38 pages,~~

~~No. 26 of 55 Copies, Series A~~

V-5426

2/91

Copy No.:

1. F. P. Allen
2-3. H. W. Bellas
4. J. S. Neill
5. J. W. Croach
6. A. A Johnson
7. E. C. Nelson
8. A. H. Peters
9. D. Baker
10. H. E. Wingo
11. R. C. Thornberry
12. V. Whatley, Jr.
13. H. E. Hootman
14. H. W. Baker
15. J. M. Boswell
16. I. M. Macafee
17. F. E. Kruesi
18. S. Mirshak
19. J. M. Morrison
20. F. D. King
21. G. F. Merz
22. W. F. Allen
23. L. G. Anderson
24. C. T. Axelberg
25. D. R. Becker
26. P. A. Dahlen
27. W. T. Dickenson
28. F. R. Field
29. L. W. Fox
30. G. H. Hair
31. E. H. Judkins
32. E. O. Kiger
33. H. A. Larson
34. J. P. Maloney
35. G. W. McManaway
36. J. T. McMurtrie
37. F. A Nuessle
38. J. H. Nuzum
39. W. M. Olliff
40. I. R. Smith
41. R. L. Spessard
42. C. J. Temple
43. O. A. Towler
44. J. E. Walls
45. W. E. Winter
46. D. A. Ward
47. J. W. Joseph
48. L. H. Martin
49. R. L. Campbell
50. R. L. Mayton
51. K. L. Gimmy
52. C. A. Bland
53. Vital Records File
54. PRD Central File
55. 706-C File

January 24, 1967

TO: L. W. FOX, 703-A

FROM: C. A. BLAND, 706-C CAB

PROCESS SYSTEM HYDRAULICS

INTRODUCTION

An analysis of hydraulic characteristics of the reactor plenum and the geometry of the permanent tube slots indicates the effect of the plenum pressure gradient on flow is substantially less than has been used previously to determine process water flows from cumulative fuel assembly resistances. The correct process water flows are about 5% less than those determined from present head available curves (Reference 1) and agree with Bingham pump data reported by the vendor (Reference 2). Better agreement between process water and cooling water heat balances also substantiate the corrected flows (Table 8).

BEST AVAILABLE COPY

[redacted]UNCLASSIFIED

January 24, 1967 [redacted] DPSP-66-1637
L. W. Fox RTR-912

Process water flow curves have been recalculated using new correlations of system losses based on pressure measurements; revised curves, equations of system losses, and additional hydraulic information are presented in this report.

SUMMARY

A comparison of reactor flows for a full reactor charge (Mark V-R) is summarized below:

	P, L or K Area		C Area	
	Previous Method	Revised Method	Previous Method	Revised Method
Plenum Pressure, Ft of D_2O at Center	180	180	180	180
Gradient, * Ft.				
Zone I	7	-2	7	0
Zone II	14	2	16	39
Zone III	16	5	-	-
Zone IV	20	12	-	-
Zone V	26	50	-	-
Zone VI	26	25	-	-
Plenum Flow, gpm	149,200	141,600	148,200	141,600
Septifoil Flow, gpm	7,000	6,600	6,900	7,100
Pump Flow, gpm	156,200	148,200	155,100	148,700
Pump Efficiency**, %	92.14	87.42	91.14	87.38

* Nominal gradient for zone from center of plenum effective for flow.

** Pump efficiency required for indicated flow.

The important points from the above table in comparison of flows from the two methods are:

[redacted]

UNCLASSIFIED

- The major effect on flow is caused by the mean Zone I plenum pressure being 7 to 9 feet less than previously assigned. Of the 600 Mark V-R assemblies, 342 in PLK and 456 in C are in Zone I. The plenum pressure gradients are shown in Figures 1, 2, 3 and 6; previous flows were based on the total head which includes velocity effects that are not wholly effective for flow.

- * A wide range of flows (± 4%) occurs within a given row of assemblies at the periphery of the plenum because of differences in orientation of permanent tube slots relative to the direction of plenum flow. The effective head above Zone V assemblies is higher than Zone IV assemblies because of their location.

- The septifoil flows are revised because of error in Reference 12. A comparison of C septifoil flow (73 septifoils) with PLK (61 septifoils) is more reasonable with the revised curves.

- The hydraulics of C are essentially identical to PLK for the same plenum pressure.

This improved calculation method has no significant effect on current individual fuel assembly operating limits and performance or on charge design because the effects are small, usually conservative, and about within the allowances that have been made for uncertainty in assembly flow in operating limits.

PROGRAM

The program for implementing the information presented in this report is as follows:

- Issue revised Technical Standards for Pump Cavitation Limits (Reference 13); have Technical Specification revised.

- Adopt correct head available curves (thereby, revising the specified process water flows) in the reactor areas beginning in January 1967; initial correct flows will be used for the January monthly report (DPSP-67-1-1).

- Collect additional data (flows, pressure, AC motor loads, and heat balance comparisons).

- Convert to this system in describing and planning new charges (SRL-AOP) as of January 1967.

Conversion to this improved method of flow calculation is desirable because it will result in:

- More consistency of reactor data with SRL/CMX tests.
- Better agreement between heat balance calculations based on process water system and cooling water system.
- Better predictions of operating parameters for special irradiations (mixed lattices).

With adoption of the improved calculation method, it is necessary to remove correction factors from the pump flow rates listed to describe the elbow cavitation curve in Technical Standard DPSTS-105-1.03 and Technical Specification 5.A.3 and 5.B.3 for PLK. No real change in reactor operation is involved. For example, the Technical Limit for a Mark V-R charge (PLK) would remain at 104°C; the new method of calculating the flow for the charge would reduce the quoted flow from 158,000 to 150,000 gpm. The new standards will reflect this better flow relationship. Limits in operating procedures are related to the measured plenum pressure, and no revision is required.

DISCUSSION

Discrepancies in process water flows determined by different methods were evident in analyses of test data obtained following installation of the Bingham pumps (Reference 3, 4, and 5). Analysis of first test results indicated a difference of about 6% between flows determined from vendor's pump data and from charge resistance. It was concluded that flow rates determined by charge resistance were more accurate, although the pumping efficiency of 91.7% (required for the higher flows indicated by this method) was recognized as suspiciously high.

Reactor flows derived from the earlier data were calculated assuming the measured pressure gradient across the plenum (extrapolated for different plenum flow conditions) was effective for flow; this assumption is incorrect and results in erroneously high flows. The measured pressure gradient, which was the total pressure drop across the plenum, includes the velocity head ($V^2/2g_c$) which is not wholly effective for flow (explained in the following paragraphs). The same incorrect assumption was made in initial hydraulic calculations for the High Flux and Curium II charges; the discrepancy between flows from vendor's data and charge resistance was larger in the small core charges than observed in standard charges because of the larger plenum pressure (10% discrepancy for Curium II - see Reference 6).

*An analysis of the effect of slot orientation indicates the total plenum pressure (static head plus velocity head) is not wholly effective for flow; the effective head is the static head plus some fraction of the plenum velocity head and differs at the entrance to the three permanent tube slots. The fraction of the velocity head effective for flow depend on orientation of the permanent tube slots relative to the direction of flow. The total pressure, static pressure and nominal effective pressure available (row average for three slots) for the Curium II charge is shown in Figure 1; the nominal effective pressure available for each row of assemblies was calculated by iteration including effects of friction loss across each row of assemblies, vectors of plenum velocities, and fraction of flow through each permanent sleeve slot. Pressure measurements during K-13 within assemblies (Reference 7) and distribution of end fitting ΔP's substantiate this effective head curve (Figures 2 and 3). The shape of the effective head curve is similar to the static pressure; therefore, the static head curve can be used for approximating the relative flow distribution in full reactor charges (i.e., Mark V-R, VI-E, etc.) with a minimal error (less than 1% error in total flow which is within the accuracy of hydraulic calculations). A comparison of the static pressure gradient and observed distribution of end-fitting ΔP's (average ΔP for similarly-zoned assemblies in a row related to head above the assemblies) for a Mark V-R charge is presented in Figure 6.

The scatter in indicated effective head in the outer rows of the reactor is attributed to effects of slot orientation and different zoned assemblies; the actual distribution of coolant is also not as well known in this region.

Based on this analysis of the plenum characteristics, the process water system hydraulics were reevaluated using the vendor's data for the Bingham pumps and system pressure measurements at different flows and temperatures (Table 6).

Bingham Pump Data

The total dynamic head (TDH) and pump efficiency (E) for different pump flows were measured at the Bingham plant for each pump before delivery to SRP. These data are presented in Reference 2 and are summarized in Tables 1, 2, 3, and 4 for each area. Average values for all pumps are presented in Table 5. Differences among individual pumps are small (less than 0.5% from average values); therefore, the average curves were used to develop head available curves in this report.

Correlation of System Loss Equations

System pressures at different flow and temperature conditions were used to correlate pressure loss equations for four different segments of the primary system; the data are summarized in Table 6. The four sections and symbols for pressure losses are as follows:

January 24, 1967 [redacted] DPSP-66-1637
L. W. Fox RTR-912

From	To	Symbol
Reactor Tank	Pump Suction Pressure Tap	ΔH_S
Pump Discharge Pressure Tap	Heat Exchanger Discharge Tap	ΔH_H
Heat Exchanger Discharge Tap	Edge of Reactor Plenum	ΔH_I
Edge of Reactor Plenum	Center of Reactor Plenum	ΔH_P

The relationship of head loss as a function of flow for each segment was correlated in the following form:

$$\Delta H = C_1 \ (\mu/\rho)^{0.2} \left(\frac{Q}{20,000}\right)^{1.8} + C_2 \left(\frac{Q}{20,000}\right)^2$$

Where:

ΔH = Loss in head, Ft of D_2O flowing

$C_1(\mu/\rho)^{0.2}\left(\frac{Q}{20,000}\right)^{1.8}$ = Friction losses sensitive to temperature (Kinematic viscosity changes)

$C_2\left(\frac{Q}{20,000}\right)^2$ = "Square law" losses and Kinetic energy changes

Q = Individual system flow at average temperature of D_2O in segment of system, gpm

C_1 and C_2 = Constants correlated from measured data

μ = Viscosity of fluid, lb/ft-sec

ρ = Density of fluid, lb/ft^3

Note: The losses in each segment of the system are calculated in ft. of D_2O at the temperature of flow; the plenum head available is the differential head across the pumps less the system losses in equivalent head at 65°C.

The constants C_1 and C_2 were evaluated from measured pressure data and system flows (from ΔH across pump) by regression analysis (calculations are presented in Reference 8). Judgement was necessary in evaluating the data because of suspected measurement errors.

[redacted]

The loss equations for each segment of the system were used to calculate the plenum head available curves shown on Figures 11 and 12 (full charges and Curium II respectively). Equations of septifoil system pressure losses as a function of flow developed in Reference 9 were used for calculating new septifoil flow curves shown on Figures 13 and 14 for full charges and Curium II respectively. The sparger jet flow is shown in Figure 15 for different plenum pressures.

Reactor Tank to Pump Suction Pressure Tap. The loss in static pressure in the reactor effluent and pump suction piping is related to flow by the following equations:

$$\Delta H_S = 19.8\ (\mu/\rho)^{0.2}\left(\frac{Q}{20{,}000}\right)^{1.8} + 7.68\left(\frac{Q}{20{,}000}\right)^2 \quad \text{for PLK}$$

$$\Delta H_S = 14.5\ (\mu/\rho)^{0.2}\left(\frac{Q}{20{,}000}\right)^{1.8} + 5.78\left(\frac{Q}{20{,}000}\right)^2 \quad \text{for C}$$

The pressure loss in C Area is less than that in PL and K because of the larger piping in C. The constants in these equations were derived by regression analysis. The data for P, L, and K at cold temperatures (Table 6) were anomalous; therefore, they were not used in the correlation. The $(Q/20{,}000)^2$ term in the above equations correlated from the data is equivalent to the velocity head at the pressure tap plus approximately 0.6 velocity head from turns and valves in the suction piping (0.6 velocity head is reasonable for these losses).

Pump Discharge Pressure Tap to Heat Exchanger Discharge Tap. The pressure loss from the pumps through the heat exchangers is correlated by the following equation:

$$\Delta H_H = 482.55\ (\mu/\rho)^{0.2}\left(\frac{Q}{20{,}000}\right)^{1.8} + 58.16\left(\frac{Q}{20{,}000}\right)^2$$

This equation is applicable for all areas; minor differences in the piping (length and turns) have an insignificant effect on the over-all losses. The major part of the loss occurs across the heat exchangers that are common in all areas.

Heat Exchanger Discharge Tap to Edge of Reactor Plenum. The loss in the inlet piping to the plenum is related to flow by the following equation:

$$\Delta H_I = 132.02\ (\mu/\rho)^{0.2}\left(\frac{Q_P}{20{,}000}\right)^{1.8}$$

[redacted]

The $(Q_p/20{,}000)^2$ term included in the previous equations is not included here because measured data indicated the velocity head recovery at the edge of the plenum was approximately equal to the "square law" losses in the piping turns and the inlet nozzles. Minor differences in the plenum inlet nozzles (between C and PLK) have an insignificant effect on the pressure loss; therefore, the above equation is applicable for all areas.

Plenum Pressure Gradient. The loss in pressure across the reactor plenum was calculated by the following equations:

$$\Delta H_P = \sum_{r=1}^{15} \Delta H_r$$

where

$$\Delta H_r = 4.55\ (\mu/\rho)^{0.2}\left(\frac{V_r}{10}\right)^{1.8}$$

ΔH_P = Total loss across reactor plenum, ft.

ΔH_r = Head loss across one row of assemblies, ft.

μ/ρ = Kinematic Viscosity, ft^2/sec

V_r = Velocity between rows of tubes, ft/sec

The above equation was derived from the empirical equation presented in Reference 10 for flow across staggered tube banks and results in good agreement with measured data as shown below:

Cycle		Plenum Flow, gpm	Temperature, °C	Plenum Head Loss, ft Measured	Calculated
C-6	Full Charge	124,800	17	23	26
P-14	Full Charge	142,200	24	30	32
C-1	High Flux (19 clusters)	72,000	10	73	66
K-13	Curium II (37 clusters)	126,000	25	94	90

The above equation is simplified for the total plenum pressure loss for full reactor charges (i.e., Mark V-R, VI-E, etc.) and Curium II charges (37 clusters) as follows:

[redacted] UNCLASSIFIED

$$\Delta H_P = 233.13\ (\mu/\rho)^{0.2}\left(\frac{Q_P}{20{,}000}\right)^{1.8}$$ Full reactor charge

$$\Delta H_P = 810.10\ (\mu/\rho)^{0.2}\left(\frac{Q_P}{20{,}000}\right)^{1.8}$$ Curium II

where

Q_P = 1/6 of plenum flow, gpm

Note: Regular flow zoning arrangements were assumed for these equations.

Comparison of Calculated with Measured Data. Losses in the different segments of the process water system calculated from the above equations are compared to measured data in Figures 6, 7, 8 and 9. The plenum head available calculated from the above equations for each test condition is compared to measured values on Figure 10. The standard error of estimate of the plenum head available for these data is 3.8%, which is equivalent to about 1.6% in plenum flow.

Septifoil System Hydraulics

Septifoil system flows are revised as shown on Figure 5 for PLK and C Area using equations for pressure losses in the system developed in Reference 9 from measured data. The total losses in the septifoil piping are summarized as follows:

$$\Delta H_{Total} = \Delta H_{Hx\text{-}Hdr} + \Delta H_{6"} + \Delta H_{1\frac{1}{4}"} + \Delta H + \Delta H_o + \Delta H_s$$

where:

ΔH_{Total} = Total loss in septifoil system piping, ft. (equivalent to heat exchanger discharge pressure)

$\Delta H_{Hx\text{-}Hdr}$ = Difference in pressure between heat exchanger discharge and septifoil header pressure tap, ft. = $2.46\left(\frac{Q_T}{1000}\right)^2$

$\Delta H_{6"}$ = Loss from septifoil header pressure tap to $1\frac{1}{4}$-inch individual septifoil supply lines, ft. = $0.23\left(\frac{Q_T}{1000}\right)^2$

$\Delta H_{1\frac{1}{4}"}$ = Loss in $1\frac{1}{2}$-inch septifoil supply line, ft. = $27.15\left(\frac{Q_S}{100}\right)^2$

ΔH = Loss in septifoil supply pin, ft. = $38.85\left(\frac{Q_S}{100}\right)^2$

ΔH_o = Loss across orifice and backup plate, ft = $22.20 \left(\frac{Q_S}{100}\right)^2$
(for Type E orifice and backup plate)

ΔH_s = Loss across sheath perforations and slots, ft. =
$0.87 \left(\frac{Q_S}{100}\right)^2$ (for Type J slotted web septifoils)

Q_T = Total septifoil flow, gpm

Q_S = Individual septifoil flow, gpm

Note: 73 septifoils in C Area; $Q_T = 73\ Q_S$

61 sepfitoils in PLK Areas; $Q_T = 61\ Q_S$

Above losses for Type J slotted web septifoils (drawing S4-1-556).

The above equation for septifoil flow was used with the equations developed for losses in the primary system to calculate the plenum head available curves in Figures 11 and 12 and the septifoil flow curves in Figures 13 and 14.

Items Affected by Revised Curves

The revised head available curves reduce values for process water flow about 5% from those presently used and alter the specified radial distribution of coolant to the fuel assemblies (relative flows of outer assemblies lower than previously specified). In no case is the effect significant enough to revise any assembly limit. Operating parameters related to flow are slightly affected, such as,

- Pressures within Assemblies
  - Channel temperature limits
  - Average assembly temperature limits
  - BOSF (saturation temperatures)
- Assembly Power
  - Slug power
  - BOSF (heat flux)
  - Sheath temperatures
  - Process water heat balance

- Parameters Related to Past Operation

  - Relative power distributions

  - Flow zoning constants

  - Productivity constants

The saturation temperatures at the exit of fuel assembly channels increases with lower specified assembly flows; therefore, operating limits are currently based on flows higher than actually exist and are conservative. The lower flows alter the pressure distribution within the channels and affect the saturation temperature (or BOSF) at different elevations in the assembly.

All parameters based on individual assembly power (i.e., slug power, heat flux, BOSF, etc.) are erroneously high and conservative. (5% flow affects BOSF by 2%)

The error in flow is largest in assemblies in the outer flow zones; therefore, the real power of these assemblies is less than currently specified. With the correct flow distribution, the power fraction of these assemblies can be up to 10% less than previously indicated; therefore, productivity constants developed from past operation for special irradiations should be revised.

Heat balances between the process water system and cooling water system have generally differed by about 5% (process system higher); this discrepancy should be resolved by the revised system flows. A comparison of heat balances using flows derived by the old and the revised methods is presented in Table 8; as shown in Table 8, the anomalies have been essentially eliminated.

<u>Items Not Affected</u>

The values for reactor power are determined from the temperature change and flow of cooling water and are, therefore, not affected by the specified process water flow. Exposure and productivity equations are refined based on 200 Area product separation experience.

The process water flows specified for High Flux charges are not as sensitive to plenum gradients and included correction factors to resolve discrepancies between resistance and Bingham pump data. The specified flows are in agreement with the revised hydraulic information in this report; therefore, the reported maximum neutron flux values achieved during the High Flux charges are considered valid.

Pump cavitation limits and shaft break flow reduction factors, although dependent on process water flows, were determined by reactor tests and related to plenum pressure; therefore, these parameters are not affected by the changes in specified system flows.

Pump cavitation limits are presented in some reports and operating procedures (i.e., Technical Standard) as a function of flow and, therefore, require revising (see Reference 13 for Technical Standard revision). The revision is to eliminate an empirical correction added to force agreement of Bingham data with reactor plenum flows (from extrapolation of test station data) that were determined erroneously.

AC Motor Load Data

Horsepower measurements at different hydraulic conditions are summarized in Table 7. Motor loads calculated from the new head available curves and the average Bingham pump data are shown for comparison. The $1\frac{1}{2}\%$ difference (average) between measured and calculated motor loads is reasonable because:

- The measurements are estimated to be accurate to $\pm$ 1%.
- The variation in average motor loads between each area is about $\pm$0.5% (from Bingham data).
- The standard error of estimate for flow using the revised head available curves is 1.6% (equivalent to $\pm$ 0.6% in motor load).

The measured data normalized to operating conditions are plotted on Figure 14.

The loading on theAC motors is the Bingham pump brake horsepower plus the energy dissipated in the gear reduced (approximately 45 hp) minus the horsepower delivered by the DC motors (75 hp at 1800 rpm).

The pump brake horsepower can be calculated from data presented in Tables, 1, 2, 3, 4, and 5 by the following equation:

$$\text{bhp} = \frac{QH\rho}{E\,(7.481)(33{,}000)}$$

where:

bhp = Pump brake horsepower

Q = Pump flow, gpm

H = Total dynamic head , ft

E = Pump efficiency

ρ = Fluid density, lb/ft^3

A loading of 3400 hp was recommended by the Engineering Department (Reference ~~10~~ 11) for the AC motors during normal operation although temporary overloads to 3450 hp were considered acceptable. Process water flows for each area which correspond to the 3400 rating are presented in Reference 14; however, these flows are based on the incorrect plenum head available curves and limited data for each area.

An analysis of the variation in flows, extrapolated from measured data in Table 7 and normalized to operating conditions (see Figure 16), corresponding to the 3400 rating indicate the small differences between areas reported previously (Reference 14) are inherent in specific motors, small flow differences, and small measurement uncertainties. Reactor flows corresponding to the 3400 hp rating are summarized below; additional data will be taken (especially in KC) to improve the extrapolations.

Reactor Flows Corresponding to AC Motor Load of 3400 hp

	Reactor System Flow, gpm*	Standard Deviation	
		gpm	HP
Measured Data			
- Maximum Motor at 3400	154,000	7,300	45
- Average Motor at 3400 or Maximum Motor at 3450	162,600	6,800	40
Calculated From Bingham Data**			
- Average Motor at 3400	167,000	-	

* Average flows extrapolated from data for all areas.

** Calculated from average data for Bingham pumps and revised head available curves.

CAB:gvb

UNCLASSIFIED

[redacted]

January 24, 1967

DPSP-66-1637
RTR-912

REFERENCES

1. Paulson, W. A., to F. E. Kruesi, "Bases for Flow Zoning SRP Reactor Charges", RTR 325, DPSP 61-2133, June 6, 1962 (Secret).

2. BPF 209325, "Total Dynamic Head Curves for Bingham Pumps".

3. Field, F. R., to A. A. Johnson, "Hydraulic Test Data - C-6", RTR-39, DPSP 57-662, April 4, 1957 (Secret).

4. Gimmy, K. L., to A. A. Johnson, "Process Water Test Data - K Area", RTR-50, DPSP 57-1142, August 23, 1957 (Secret).

5. Gimmy, K. L, to A. A. Johnson, "Bingham Startup Test Data - P and R", RTR-144, DPSP 59-794, April 17, 1959 (Secret).

6. WTD Monthly Progress Report for August, 1966, DPSP 66-1-8, p 118 (Secret).

7. TA 1-1577, "Pressure-Tap Upper Plugs", DPSOX 6597, August 19, 1966 (Unclassified).

8. Bland, C. A., "Process System Hydraulic Calculations", DPSP 66-972, December 14, 1966 (Secret). ✓

9. Bland, C. A. and J. M. Morrison, "Septifoil Calculations Notebook", DPSPU 66-138, December 14, 1966.

10. Perry, John H., Chemical Engineers' Handbook, Fourth Edition, McGraw-Hill, New York (1963), pp 5-47.

11. Singleton, F. D. and J. B. Tinker, letter to D. A. Miller and G. B Carlton, "3400 HP AC Motors Driving Bingham Pumps", November 9, 1956.

12. Temple, C. J., to F. E. Kruesi, "Shaft Break Flow Reductions", RTR 294, DPSP 60-1286, March 10, 1961 (Secret).

13. Bland, C. A., "Savannah River Plant Technical Standard Revision Proposal - Heavy Water Temperatures", DPSP 66-1675, January 16, 1967 (Secret).

14. WTD Monthly Progress Report for May 1966, DPSP 66-1-5, p 133 (Secret).

[redacted] SIFIED

January 24, 1967

UNCLASSIFIED
[redacted]

DPSP-66-1637
RTR-912

Table 1

Bingham Pump Data - P Area

System	1		2		3		4		5		6	
Pump Serial #31799 -	23		20		22		21		24		25	
Flow, gpm	TDH	E	TDH	E	TDH	E	TDH	E	TDH	E	TDH	E
0	566.5	-	562.7	-	568.9	-	566.5	-	565.5	-	547.4	-
6,000	538.9	45.0	536.6	45.6	538.9	45.1	538.9	45.0	535.9	44.9	533.4	45.4
10,000	523.4	64.1	523.1	65.2	527.8	63.4	523.4	64.1	524.2	65.2	520.5	63.4
14,000	510.2	76.0	509.5	76.4	512.5	76.1	510.2	76.0	508.8	76.3	506.2	75.4
18,000	488.6	83.2	487.9	83.9	492.7	83.9	488.6	83.2	487.6	84.0	484.2	83.6
22,000	457.8	86.8	456.7	87.5	458.0	86.9	457.8	86.8	455.3	87.4	451.7	86.9
25,000	429.9	87.7	427.1	87.8	429.5	87.6	429.9	87.7	427.0	88.1	424.0	87.7
28,000	393.1	86.6	390.6	86.8	392.1	86.6	393.1	86.6	390.9	86.8	385.0	86.3
30,000	365.2	84.4	360.2	84.2	362.5	83.8	365.2	84.4	361.9	84.8	353.5	83.8

[redacted] UNCLASSIFIED

Table 2

Bingham Pump Data - L Area

System	1		2		3		4		5		6	
Pump Serial #31799-	14		17		15		18		16		19	
Flow, gpm	TDH	E	TDH	E	TDH	E	TDH	E	TDH	E	TDH	E
0	556.3	-	568.2	-	567.7	-	560.2	-	568.5	-	563.4	-
6,000	535.0	45.8	540.7	46.3	541.2	45.4	537.6	44.7	543.1	46.1	539.3	45.0
10,000	524.5	64.1	527.5	64.2	529.2	64.8	524.8	62.2	531.3	64.8	525.3	62.1
14,000	511.1	75.8	513.7	76.1	514.1	76.1	510.1	75.5	516.3	77.3	509.2	75.4
18,000	486.9	83.9	491.9	83.6	492.8	83.6	487.0	82.2	493.5	84.1	488.1	83.3
22,000	455.6	86.4	457.1	86.9	461.7	86.7	454.8	86.3	459.4	87.4	453.9	86.2
25,000	426.7	87.8	426.2	87.7	432.7	87.3	425.4	86.9	428.0	88.2	425.8	87.6
28,000	391.7	86.8	389.4	86.1	396.6	86.4	388.8	86.0	391.8	86.4	387.5	86.0
30,000	364.0	85.0	357.8	83.4	368.6	84.6	360.1	83.3	362.0	84.4	357.4	83.4

[redacted]

Table 3

Bingham Pump Data - K Area

System	1		2		3		4		5		6	
Pump Serial #31799-	12		13		10		9		8		11	
Flow, gpm	TDH	E	TDH	E	TDH	E	TDH	E	TDH	E	TDH	E
0	552.4	-	552.3	-	566.6	-	564.3	-	565.5	-	557.4	-
6,000	535.6	46.4	539.1	46.1	538.4	45.6	538.6	46.2	538.8	45.4	539.8	45.2
10,000	524.9	65.1	527.4	65.2	528.9	65.0	529.3	65.5	526.5	64.7	528.2	64.8
14,000	508.9	77.1	512.7	76.8	513.3	75.8	512.1	76.3	511.3	76.1	513.8	76.1
18,000	487.1	83.9	492.4	84.1	488.9	82.7	491.9	83.8	491.0	83.3	494.5	83.7
22,000	453.8	86.8	456.9	86.6	453.4	85.9	457.2	86.8	457.6	86.5	462.6	86.6
25,000	422.5	87.4	425.5	87.5	423.8	86.4	426.4	87.3	426.0	87.0	432.7	87.4
28,000	387.3	86.2	387.7	85.8	388.4	85.9	389.5	85.9	390.4	85.9	398.8	86.4
30,000	359.7	84.9	359.1	83.7	356.0	82.8	358.4	83.1	361.4	83.6	370.3	84.6

UNCLASSIFIED

[redacted]

Table 4

Bingham Pump Data - C Area* - Original Impellers

System	1		2		3		4		5		6	
Pump Serial #31799-	7		2		3		4		5		6	
Flow, gpm	TDH	E	TDH	E	TDH	E	TDH	E	TDH	E	TDH	E
0	565.1	-	559.7	-	551.2	-	548.1	-	558.2	-	562.2	-
6,000	535.6	45.8	539.2	46.4	532.3	45.7	539.2	46.2	536.8	46.3	534.0	45.7
10,000	523.7	65.1	528.9	65.3	523.2	62.9	528.4	65.3	525.6	65.0	521.2	65.2
14,000	509.1	76.1	516.5	76.6	508.9	75.8	514.1	76.8	507.6	76.7	508.2	76.0
18,000	486.6	84.0	490.4	83.8	488.6	84.2	493.3	84.2	487.9	84.4	487.7	84.0
22,000	453.7	87.2	455.8	86.8	455.9	87.7	459.8	87.0	454.8	87.1	452.6	86.4
25,000	422.0	87.2	423.3	86.7	424.3	87.7	431.0	88.2	423.4	87.5	421.2	86.7
28,000	383.6	86.1	388.7	86.3	388.1	86.8	395.6	86.9	387.7	86.4	385.0	85.8
30,000	356.3	83.8	360.5	84.3	361.0	84.7	367.3	85.0	359.3	84.1	355.0	83.3

* The impellers originally in the C Area pumps were replaced with the impellers from R Area pumps following the High Flux program in 1966 because of excessive cavitation damage in the eye of the impeller.

January 24, 1967 [redacted] DPSP-66-1637
RTR-912

Table 5

Bingham Pump Data - Average of All Pumps

System Flow, gpm	Total Dynamic Head, ft	Pump Efficiency, %	
0	561.05	-	28.5
6,000	537.80	45.60	25.3
10,000	525.98	64.35	
14,000	511.20	76.18	
18,000	489.58	83.70	
22,000	456.23	86.79	
25,000	426.15	87.44	
28,000	389.83	86.29	
30,000	360.60	84.02	

[redacted]

Table 6

Process Water System Data*

Cycle	Type Charge	Pump ΔH	Pump Flow	Pump Temp	Pump Suction Loss, ΔH_S	Heat Exchanger ΔH_H	Heat Exchanger Flow	Heat Exchanger Temp+	Plenum & Inlet $\Delta H_I + \Delta H_P$	Plenum & Inlet Flow	Plenum & Inlet Temp	Plenum** Head
R-1	Mark VII-A	418.7	23,400	28.0	14.5	141.7	23,400	28.0	48.6	23,400	28.0	214.0
R-1	Mark VII-A	412.9	23,900	30.0	15.3	146.0	23,900	30.0	47.7	22,763	30.0	203.9
P-14	Mark VII-A	41.53	23,700	24.0	14.4	141.3	23,700	24.0	50.6	23,700	24.0	209.1
P-14	Mark VII-A	410.6	24,150	24.0	15.6	146.9	24,150	24.0	48.5	22,963	24.0	199.7
K-11	Mark VI	447.3	20,800	24.0	12.6	112.8	20,000	24.0	41.1	20,800	24.0	282[illegible]
K-11	Mark VI	440.5	21,500	24.0	13.5	121.1	21,500	24.0	35.5	20,172	24.0	271.[illegible]
C-6	Mark VI	448.2	20,800	17.0	7.8	125.7	20,800	17.0	34.7	20,800	17.0	280.[illegible]
C-6	Mark VI	439.9	21,500	17.0	8.5	130.1	21,500	17.0	36.3	20,150	17.0	265[illegible]
P-9	Mark V-R	400.7	24,900	92.3	14.4	155.1	24,507	67.3	43.3	23,135	42.2	180[illegible]
L-6	Mark VI-E	398.9	25,100	91.6	14.4	146.6	24,704	66.4	34.9	23,314	41.4	195[illegible]
K-14	Mark XII	433.4	22,200	75.3	11.5	126.8	21,956	54.4	108.9	20,528	33.5	181.3
C-4	Mark V-B	393.4	25,300	94.1	10.9	152.5	24,860	67.1	46.9	23,838	40.1	175.3
C-10	Curium I	375.3	26,850	81.0	12.6	170.0	26,514	59.5	52.3	25,142	37.9	148.0

* All flows and losses (ΔH) are in gpm and feet, respectively, at temperature (°C) of fluid; system flows were determined from pump ΔH curve (Table 5). System pressures were measured with Heise gages.

** Measured head at center of plenum at Zero elevation (excluding blanket gas pressure).

\+ Average temperature of heat exchanger flow is average of reactor effluent and plenum inlet.

7. Summary of AC Motor Load Measurements

-2	K-11	K-14	K-11	K-11	C-6	C-10	C-11	C-21	C-2
k VI-B	Mark VI	Mark V-B	Mark XII	Mark XII	Mark VI	Cm-I	Cm-I	Hi ∅	Mark V-B
/29/65	7/-/57	11/19/65	7/29/66	8/3/66	2/-/57	9/14/64	9/30/64	11/23/65	5/5/66
.2	271.9	184.3	196.0	188.0	265.0	148.0	162.2	382.3	174.8
,960	21,500	24,860	22,230	22,400	21,500	26,090	25.760	14,220	25,330
.2	24.0	90.0	25.0	72.7	17.0	81.0	90.6	72.0	89.0
(2)	(1)	(2)	(2)	(2)	(1)	(1)	(1)	(2)	(2)
3256	3000	3270	3184	3170	3100	3333	3280	2412	323[illegible]
3245	3042x	3270	3159	3147	3205	3334	3290	2497x	321[illegible]
3245	3021	3245	3184	3170	3126	3356	3320	2460	319[illegible]
3256	3011	3319	3232	3221	3231x	3446x	3400x	2484	328[illegible]x
3240	3021	3277	3154	3154	3061	3382	3271	2412	3199
3277x	3032	3362x	3240x	3232	3139	3374	3333	2473	3199
3253	3021	3290	3192	3182	3144	3371	3316	2456	3221
3175	3137	3226	3182	3164	3140	3294	3262	2534	3282

ate method of measurement: (1) 151 Building watt-hr meter (2) Weston precision Test

d Temp Conditions; 75 hp from DC motors and 45 hp dissipated in gear reducer.

UNCLASSIFIED

[redacted]

Table 8

Reactor System Heat Balance Data

Area	Reactor* Power	Process Water Heat Balance** Old Method	Process Water Heat Balance** Revised Method
		/Power, MW/	
P	2525	2595	2479
L	2389	2498	2369
K	1894	-	1862
C	2475	2516	2437
		/Normalized to Reactor Power/	
P	1.000	1.028	0.982
L	1.000	1.046	0.992
K	1.000	-	0.983
C	1.000	1.017	0.985

* Reactor power calculated by cooling water flow and temperature change.

** Heat balance across heat exchangers.

[redacted]

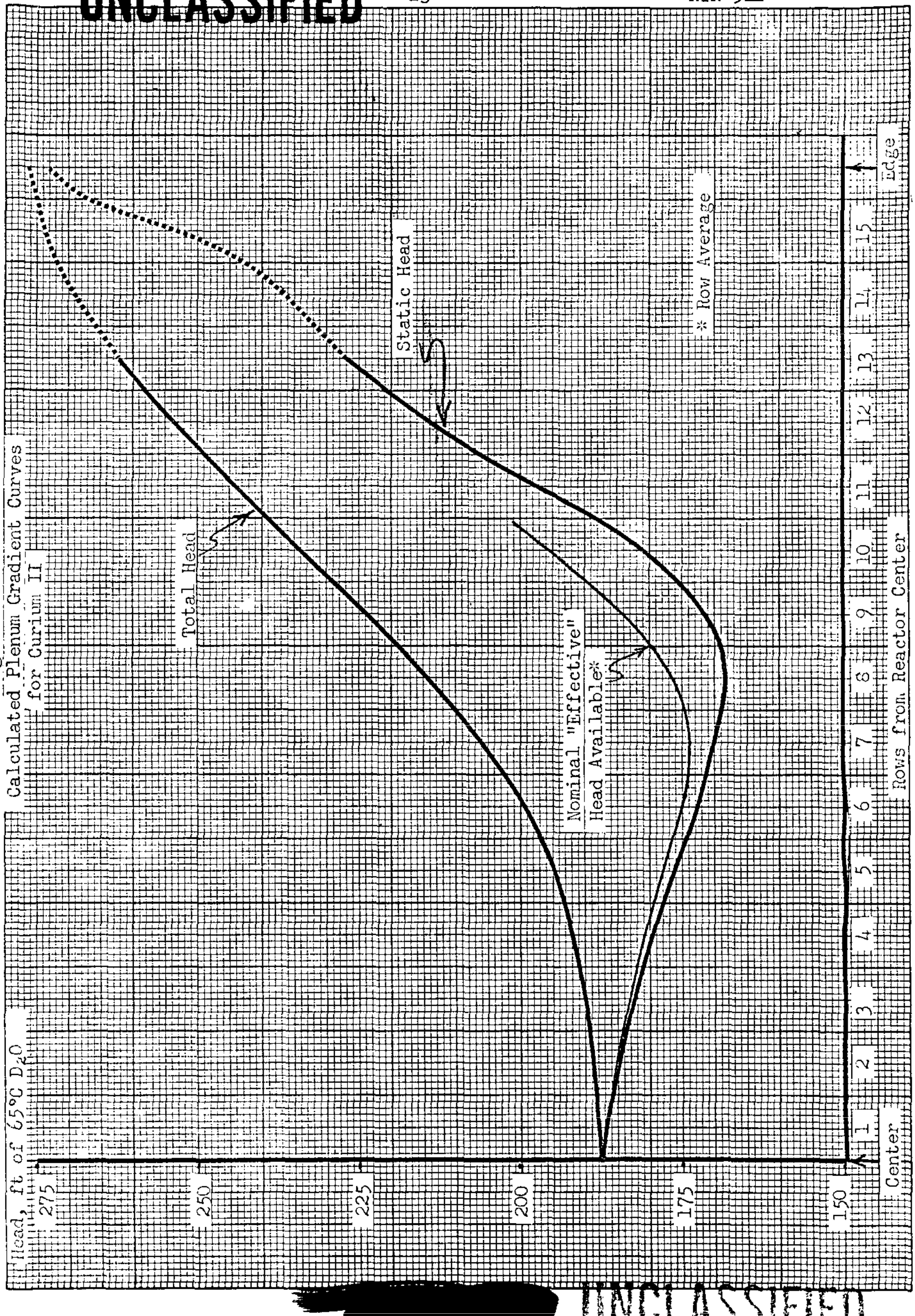


Figure 1
Calculated Plenum Gradient Curves for Curium II

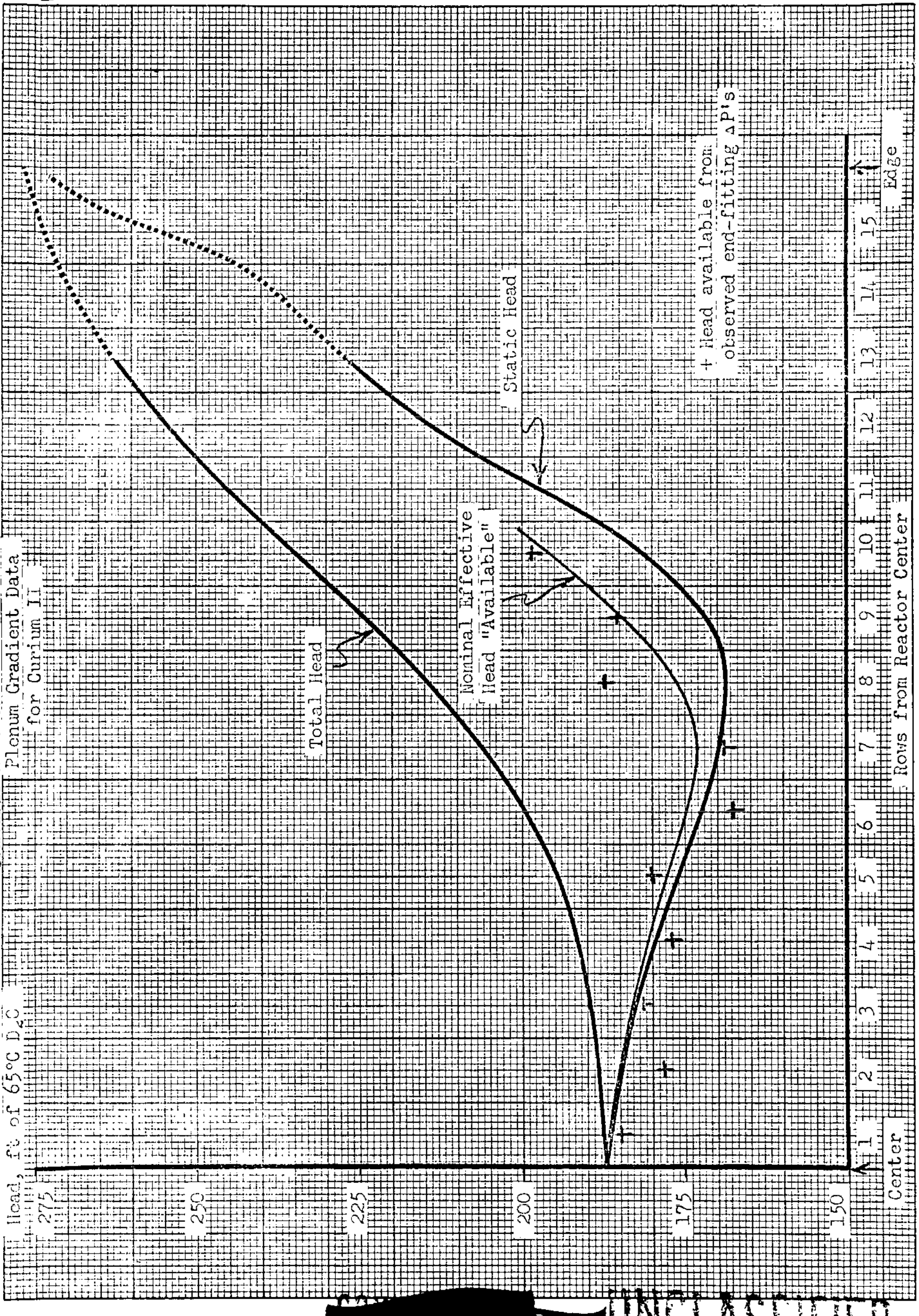
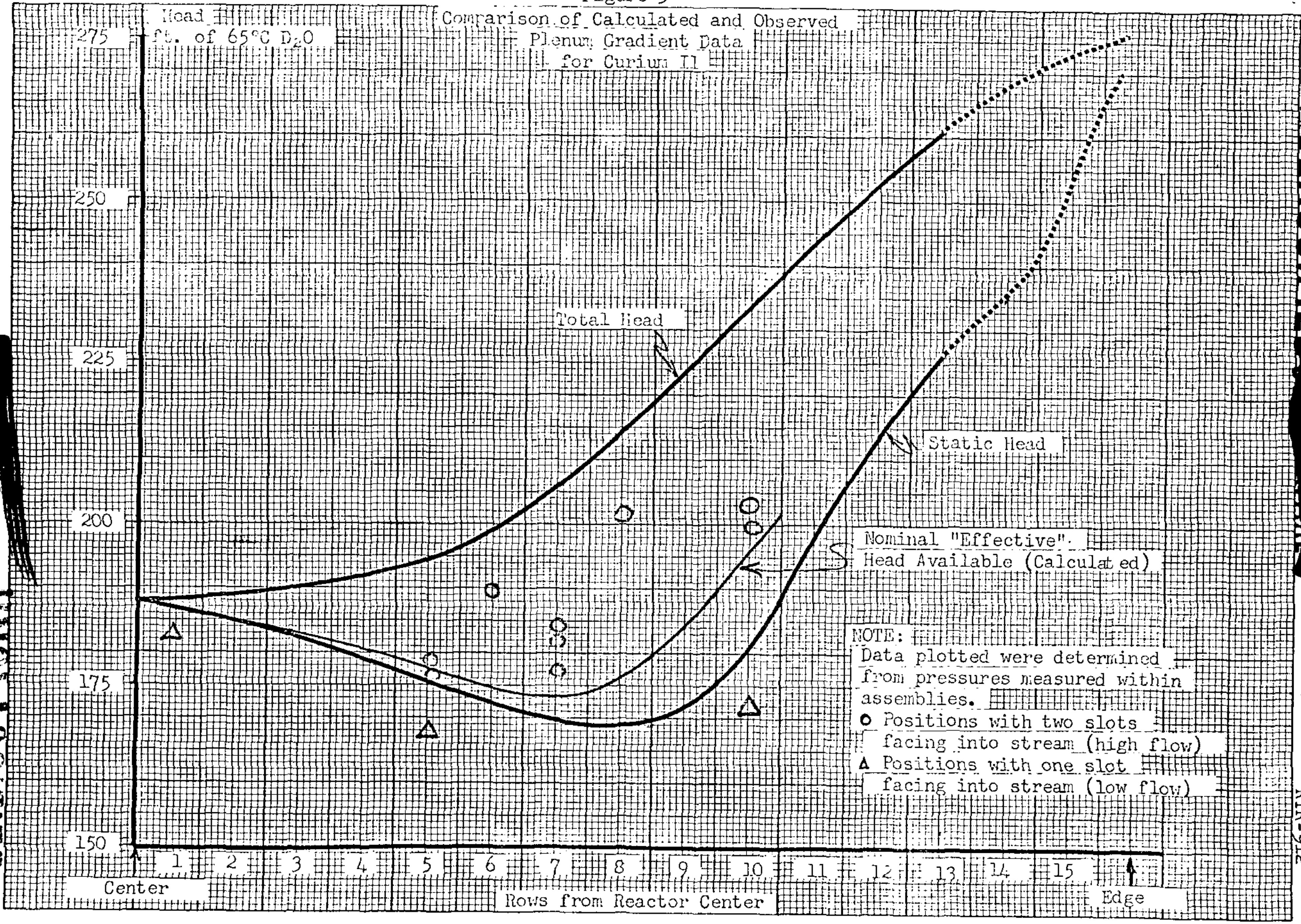


Figure 2
Comparison of Calculated and Observed
Plenum Gradient Data
for Curium II

Figure 3



Comparison of Calculated and Observed Plenum Gradient Data for Curium II

DPSP-66-1367
RTR-912

Figure 4

Comparison of Old and Revised Plenum Head Available Curves

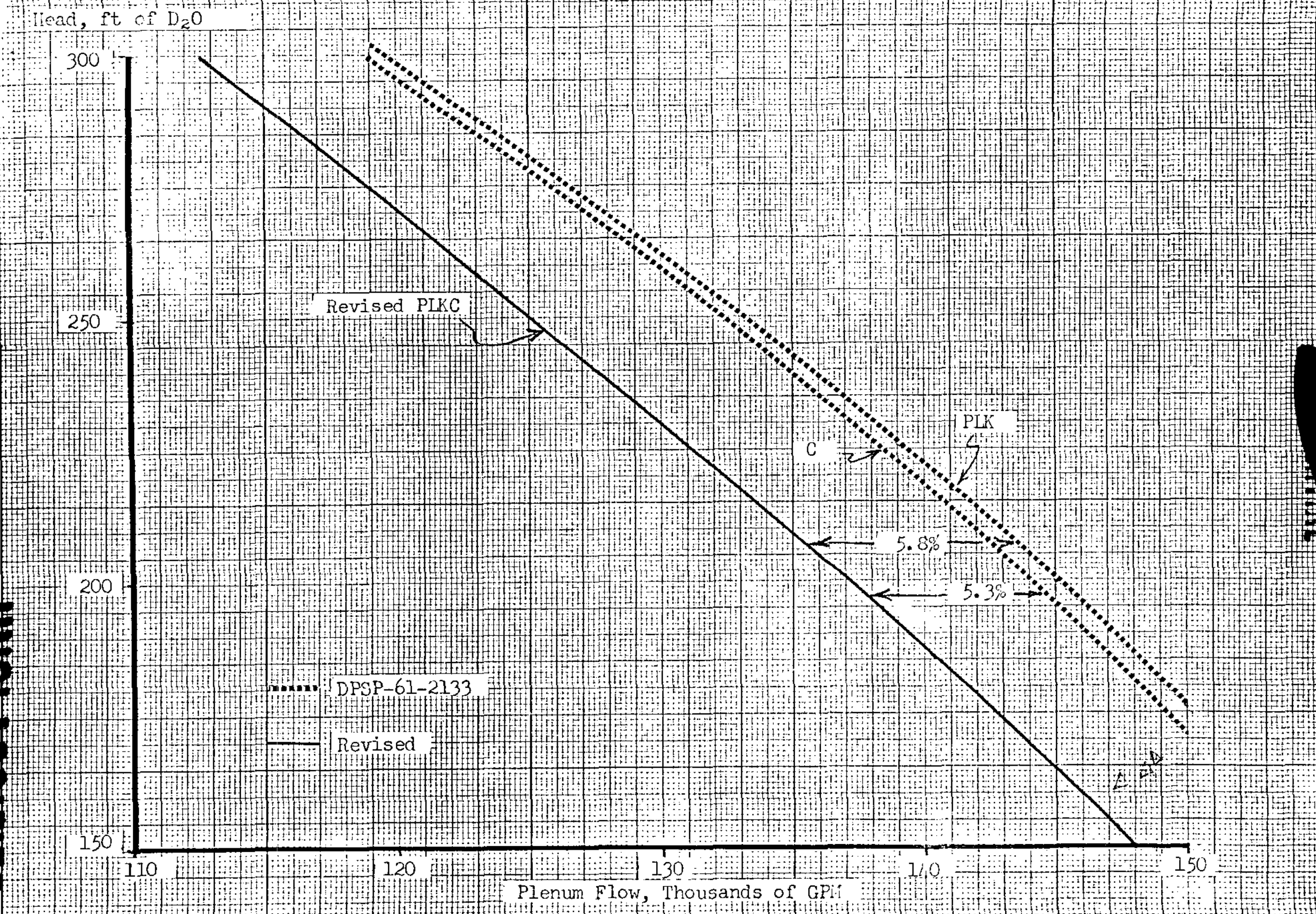
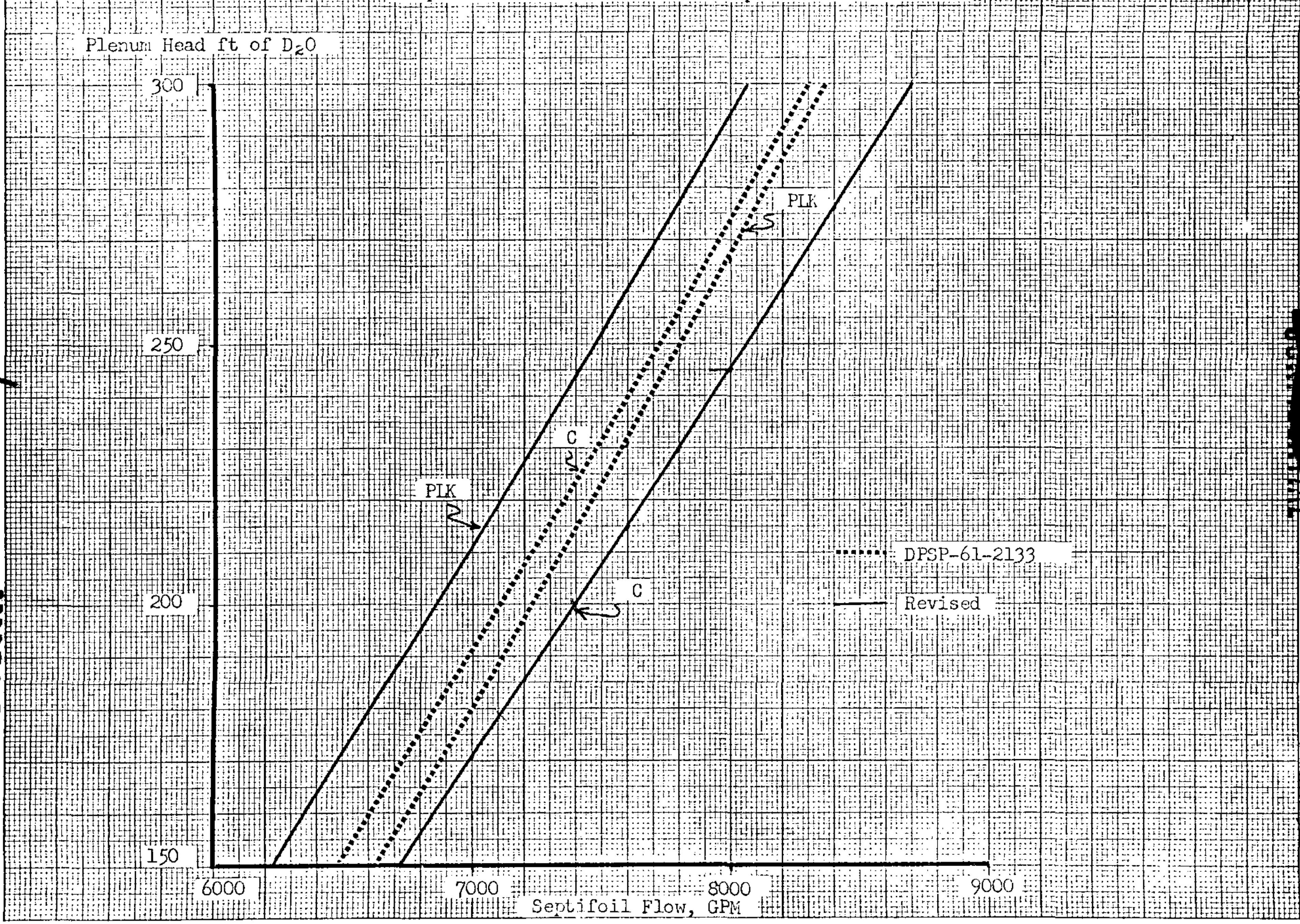


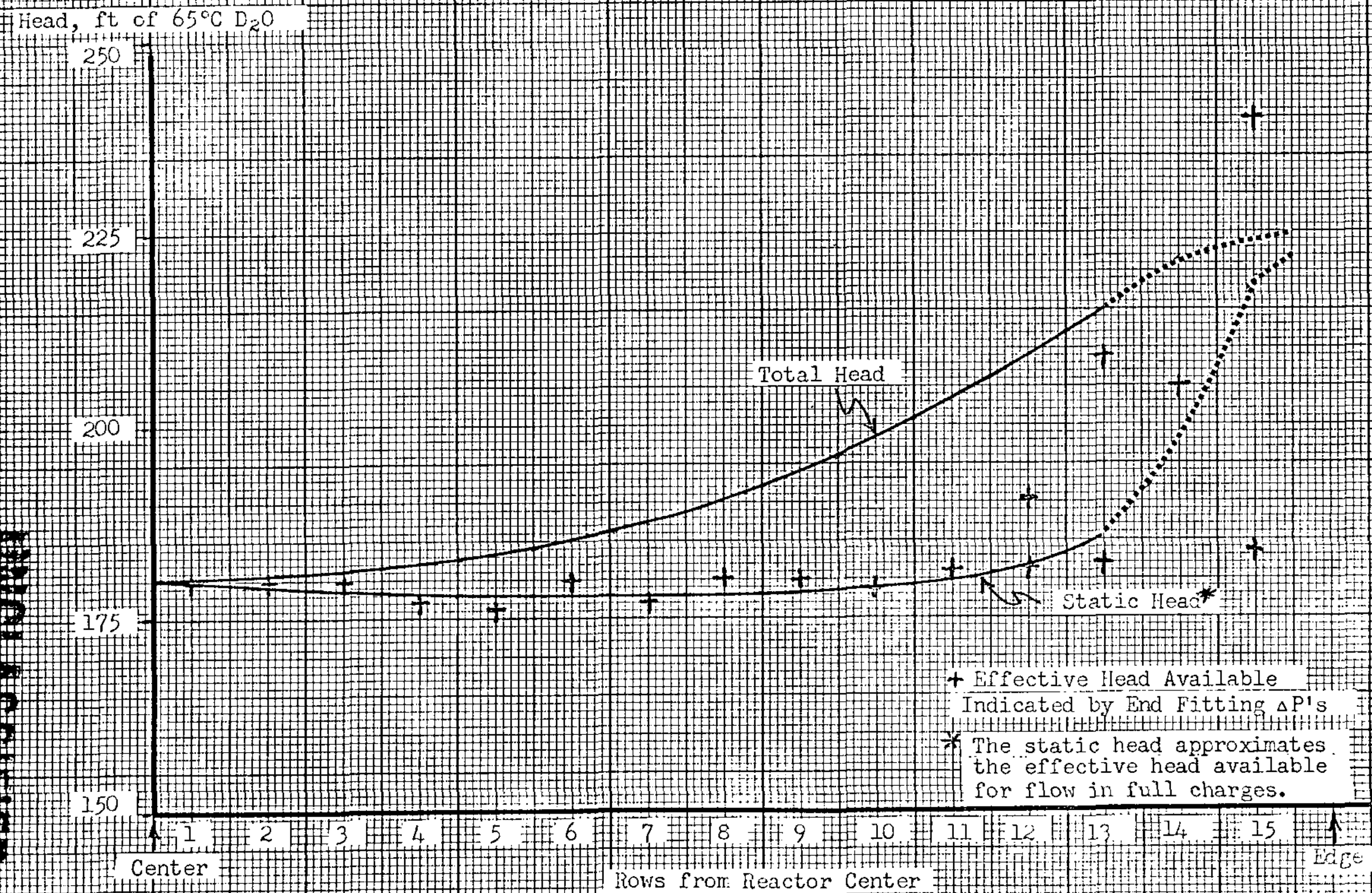
Figure 5

Comparison of Old And Revised Septifoil Flow Curves



DPSP-66-1367
RTR-912

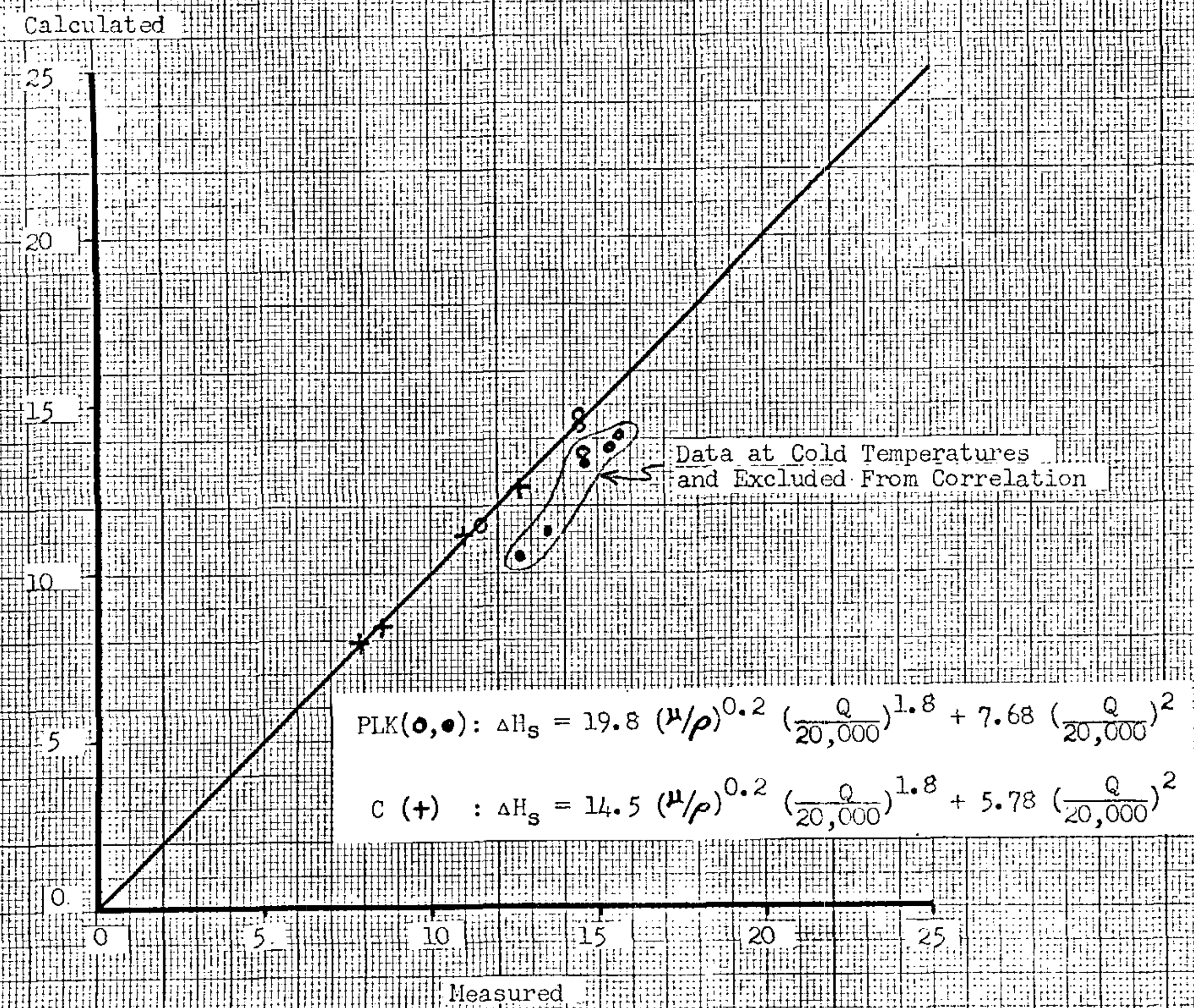
Figure 6
Comparison of Calculated and Observed
Reactor Plenum Gradient Curves
for Mark V-R Charge



DPSP-66-1367
RTR-912

Figure 7

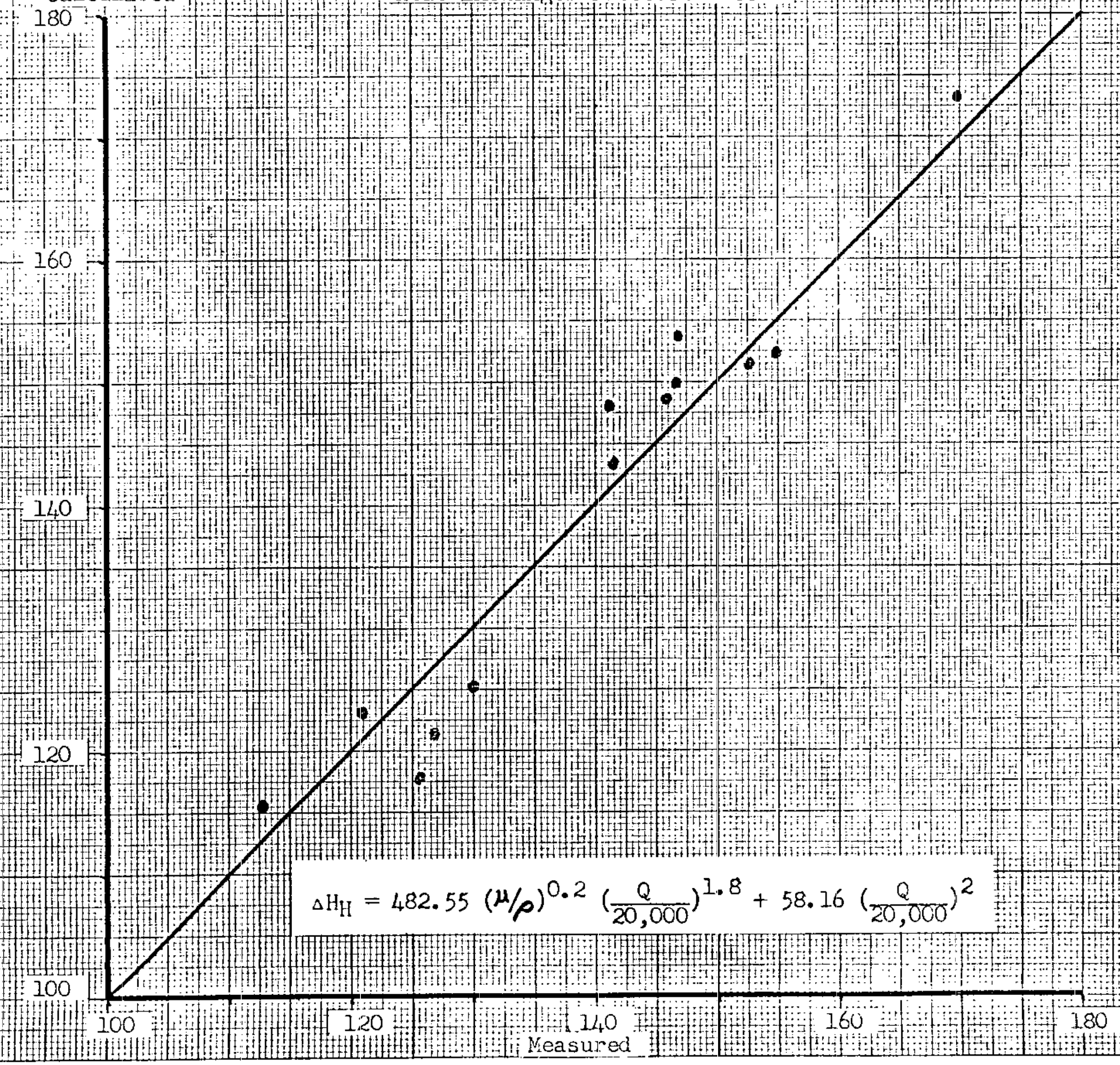
Comparison of Calculated and Measured Suction Piping Pressure Loss



PLK(o,•): $\Delta H_s = 19.8\ (\mu/\rho)^{0.2}\ \left(\frac{Q}{20,000}\right)^{1.8} + 7.68\ \left(\frac{Q}{20,000}\right)^{2}$

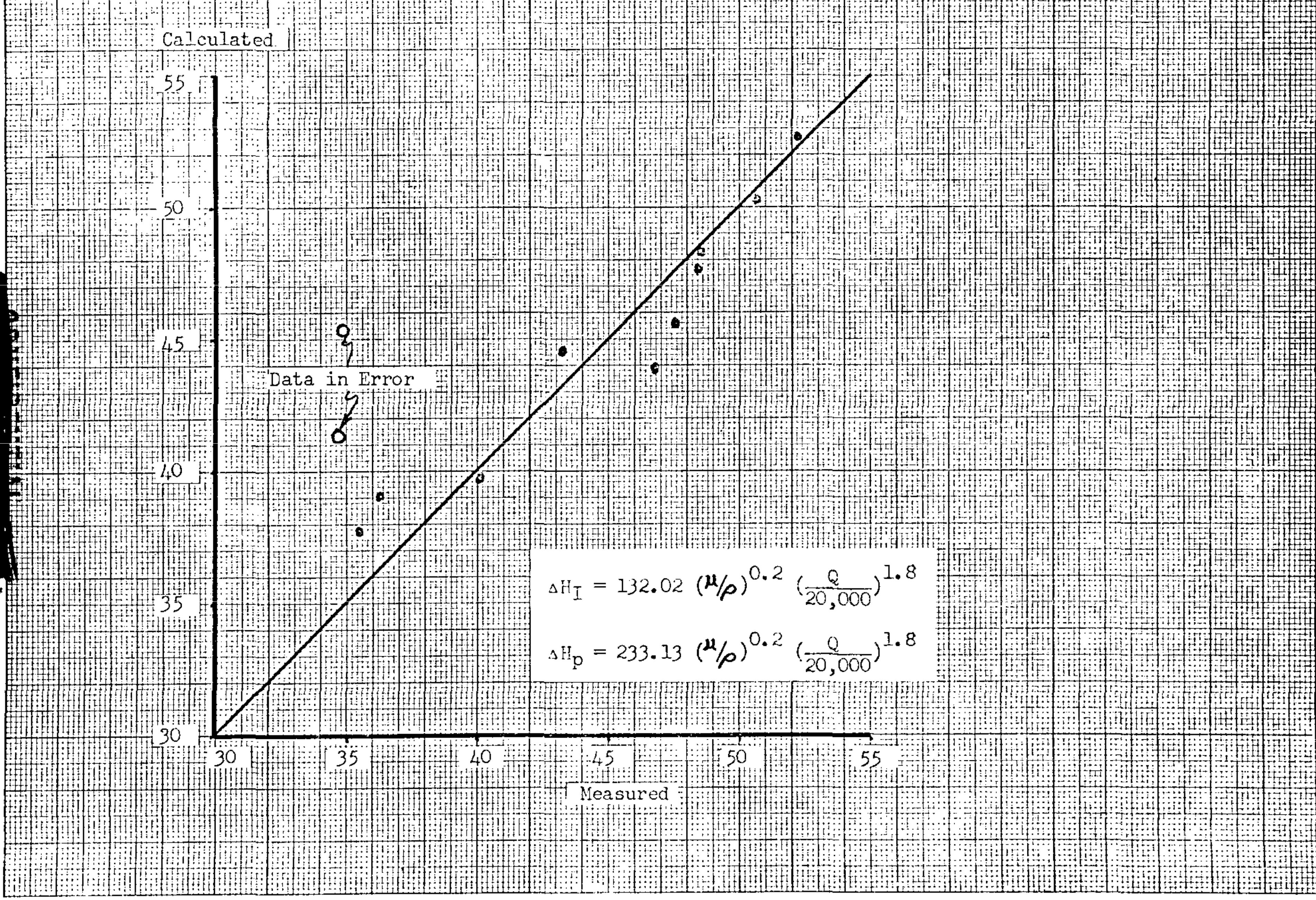
C (+) : $\Delta H_s = 14.5\ (\mu/\rho)^{0.2}\ \left(\frac{Q}{20,000}\right)^{1.8} + 5.78\ \left(\frac{Q}{20,000}\right)^{2}$

Figure 8
Comparison of Calculated and Measured
Heat Exchanger Pressure Loss



$$\Delta H_H = 482.55\ (\mu/\rho)^{0.2}\ \left(\frac{Q}{20,000}\right)^{1.8} + 58.16\ \left(\frac{Q}{20,000}\right)^{2}$$

Figure 9
Comparison of Calculated and Measured Plenum
and Inlet Piping Pressure Loss



[redacted]

DPSP-66-1367
RTR-912

Figure 10

Comparison of Calculated and Measured Plenum Head Available

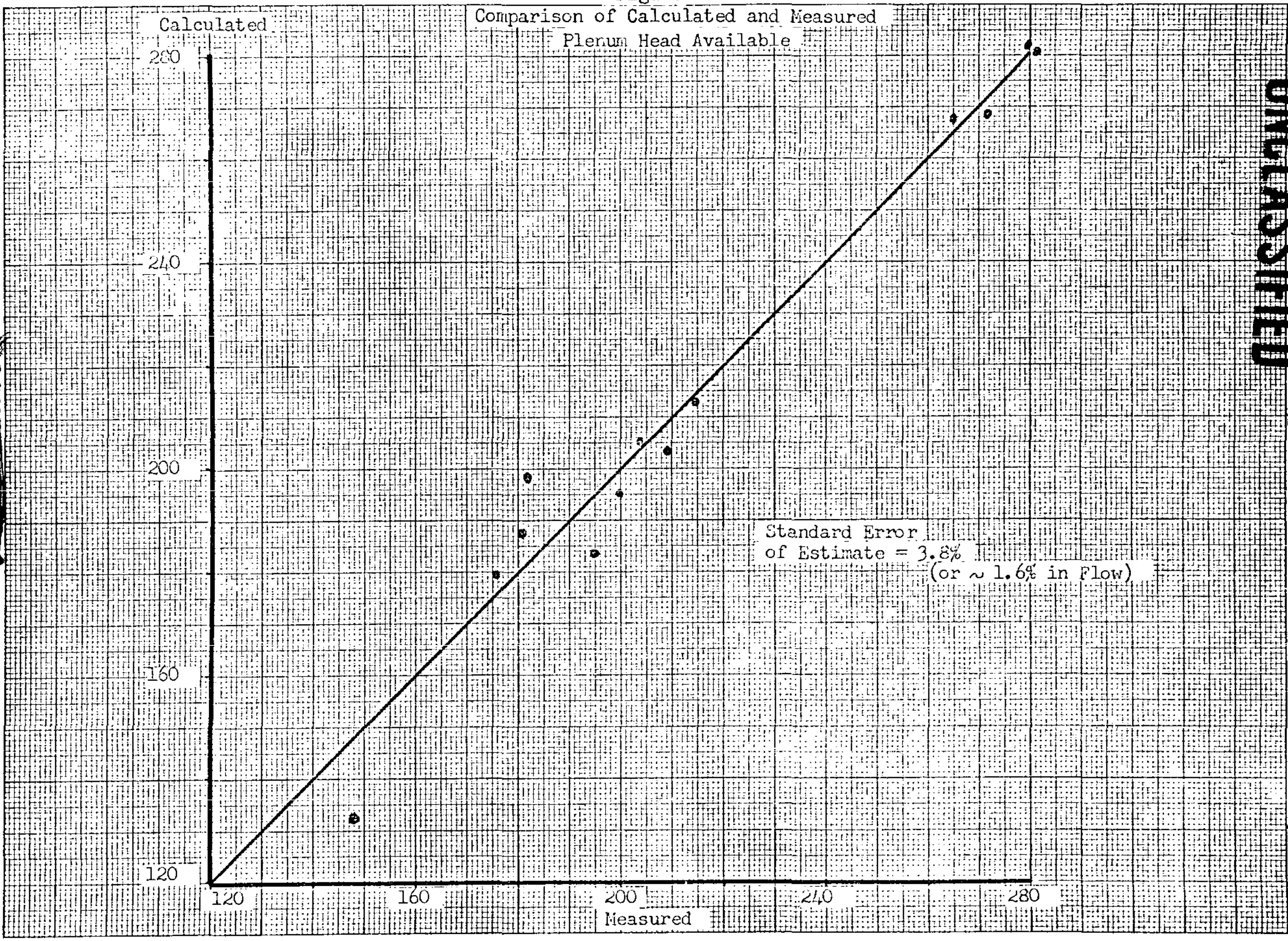
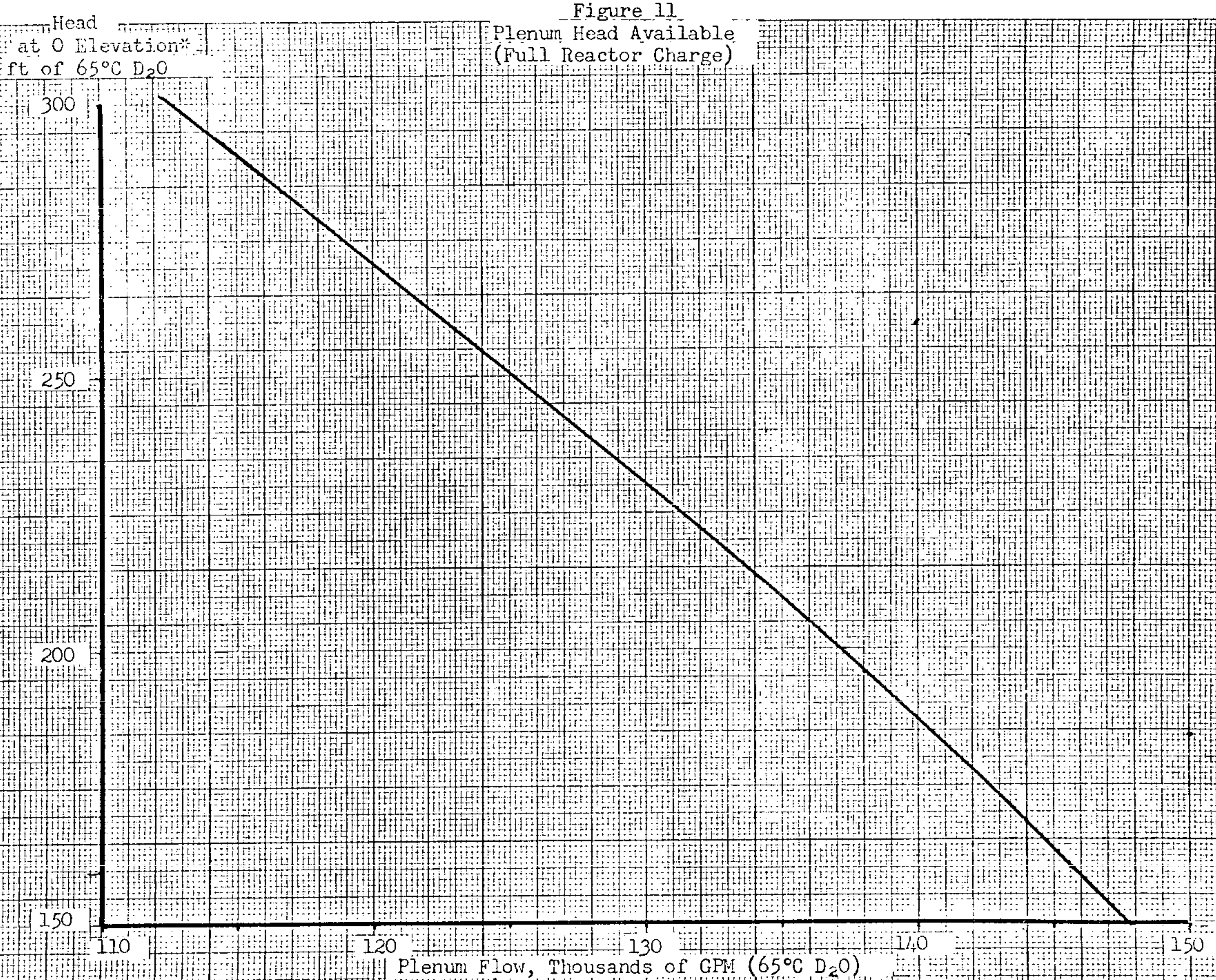
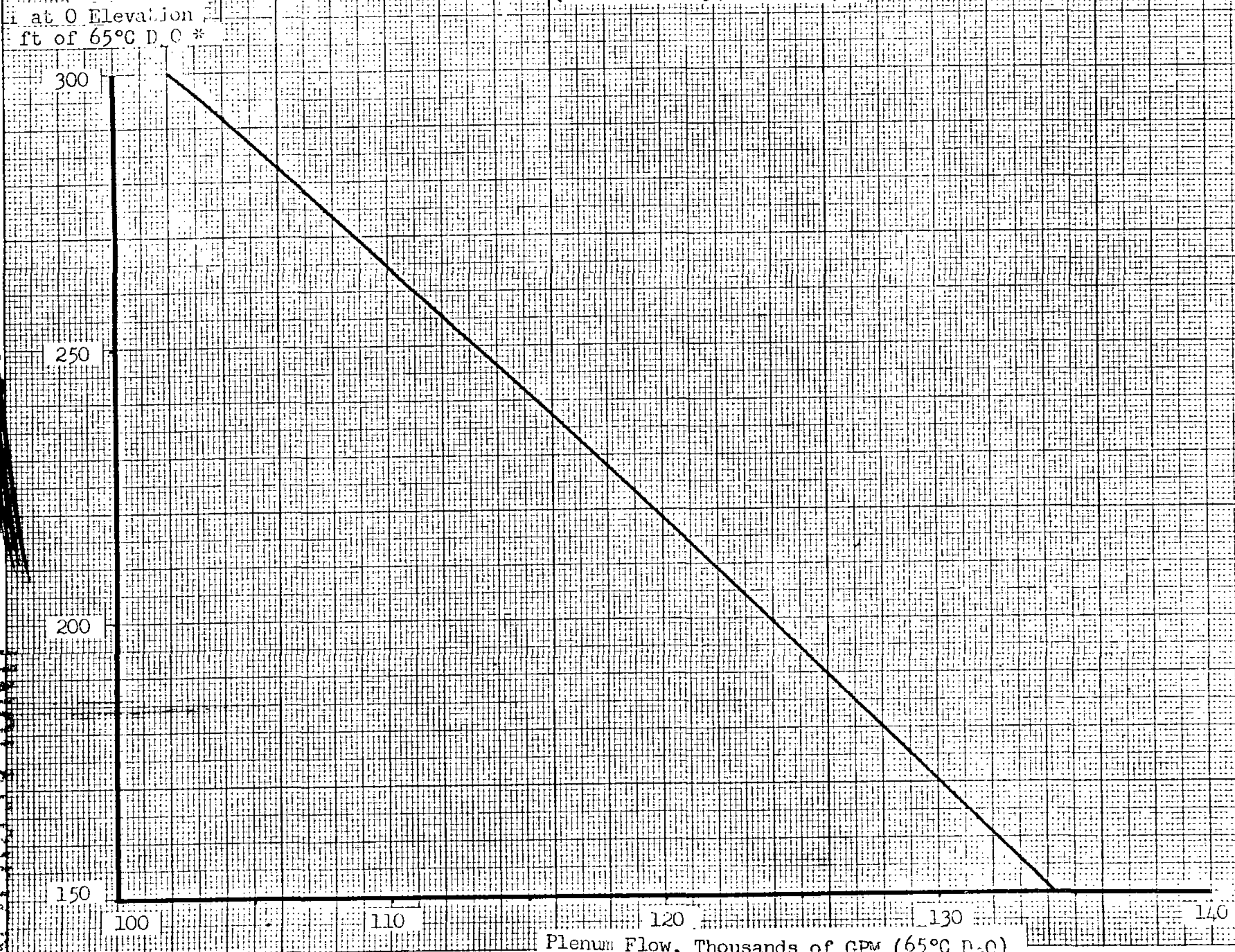


Figure 11
Plenum Head Available
(Full Reactor Charge)



* Excludes Blanket Gas Pressure

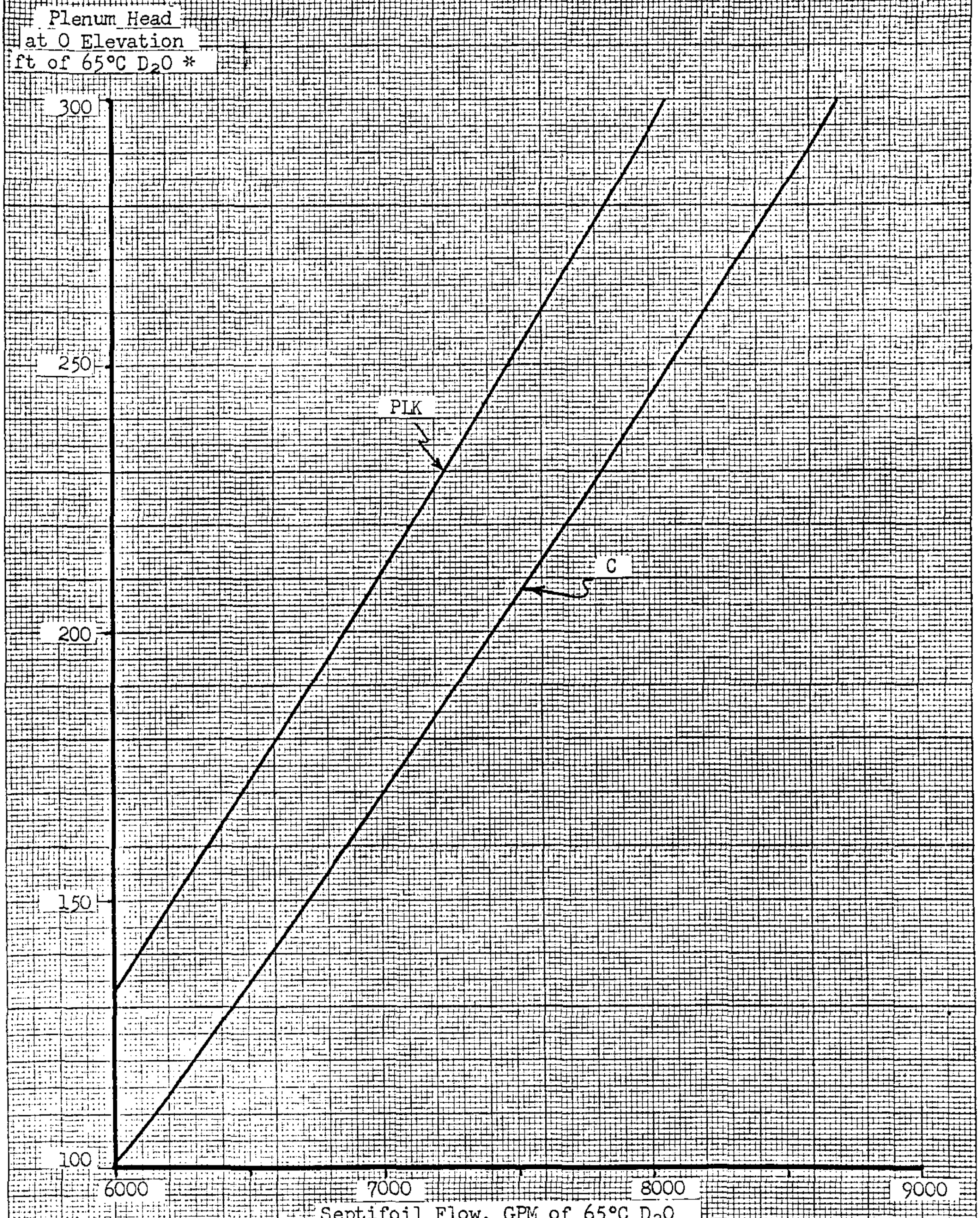
Figure 12
Plenum Head Available
(Curium II - 37 clusters)



* Excludes Blanket Gas Pressure

DPSP-66-1367
RTR-912

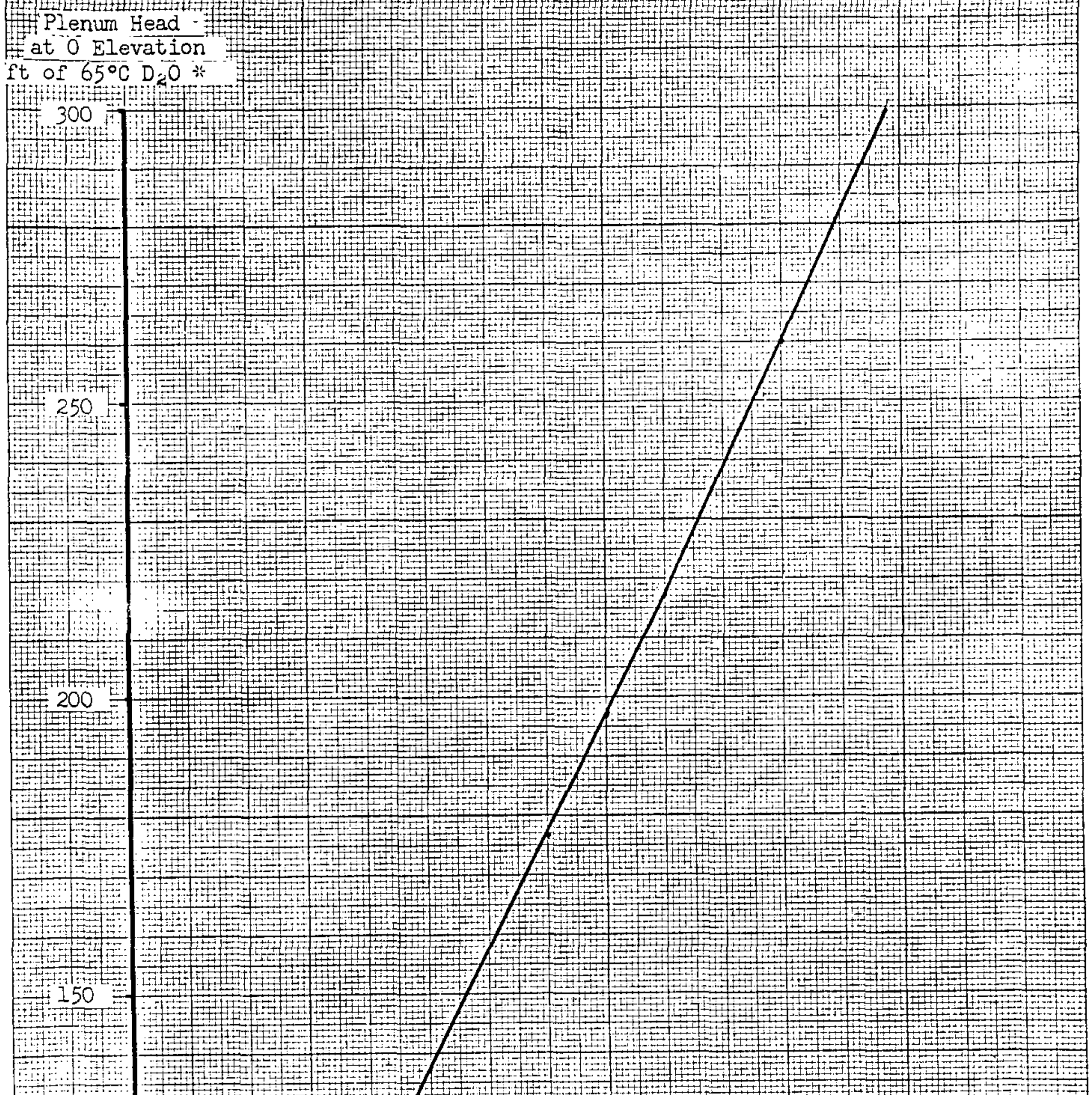
Figure 13
Septifoil Flow
Full Reactor Charge



* Excludes Blanket Gas Pressure

UNCLASSIFIED [redacted] DPSP-66-1367
RTR-912

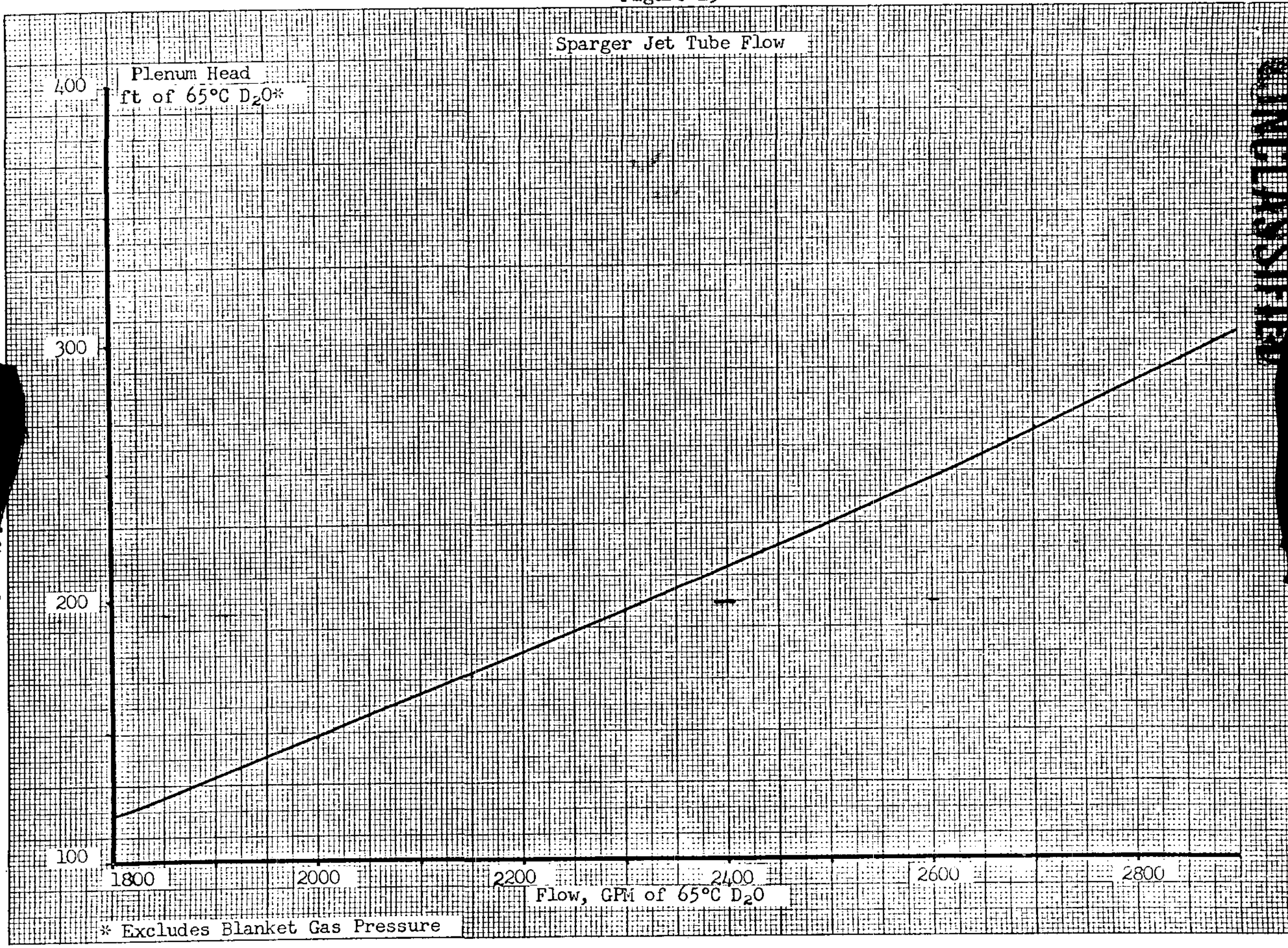
Figure 14
Septifoil Flow
(Curium II - 37 clusters of fuel)



* Exlcudes Blanket Gas Pressure

[redacted] UNCLASSIFIED

Figure 15


Sparger Jet Tube Flow
Plenum Head
ft of 65°C D2O*
400
300
200
100
1800
2000
2200
2400
2600
2800
Flow, GPM of 65°C D2O
* Excludes Blanket Gas Pressure

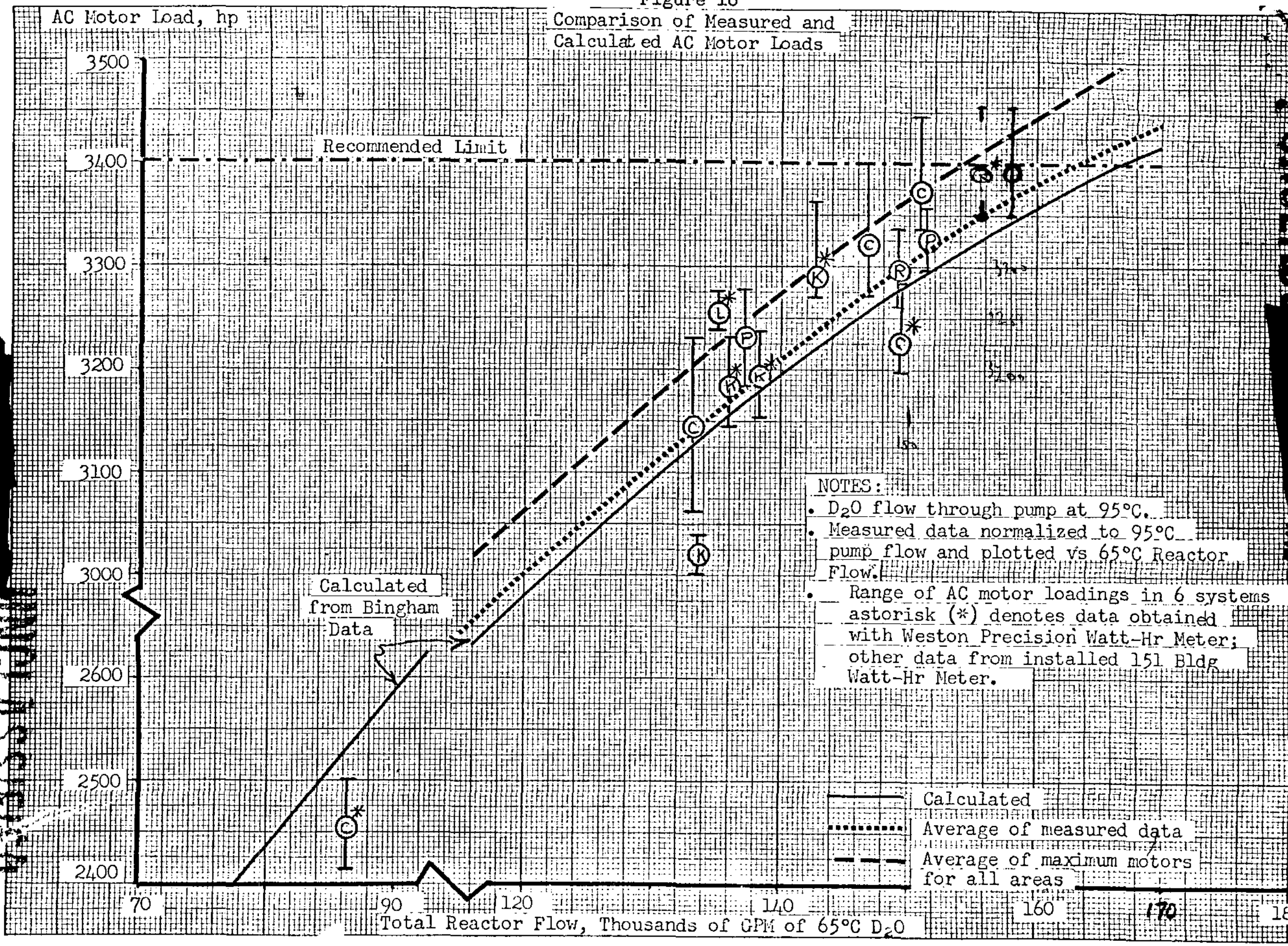


Figure 16
Comparison of Measured and Calculated AC Motor Loads