

Indiana & Michigan Electric Company

ANNUAL REPORT 1978

AMERICAN ELECTRIC POWER SYSTEM

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The Company's Annual Report
(Form 10-K) to the Securities and
Exchange Commission will be available
on or about March 31, 1979 to shareowners
upon their written request and at no cost.
Please address such requests to:

Mr. H. D. Post
Assistant Treasurer
American Electric Power
Service Corporation
2 Broadway
New York, N. Y. 10004

Transfer Agent of Cumulative Preferred Stock

Morgan Guaranty Trust Company of New York
30 West Broadway, New York, N. Y. 10007

Registrar of Cumulative Preferred Stock

Irving Trust Company 1 Wall Street, New York, N. Y. 10015

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Background of the Company

INDIANA & MICHIGAN ELECTRIC COMPANY (the Company) is a subsidiary of American Electric Power Company, Inc. (AEP) and is engaged in the generation, purchase, transmission, and distribution of electric power. The Company was organized under the laws of Indiana on February 21, 1925, and is also authorized to transact business in Michigan and West Virginia. Its principal executive offices are in Fort Wayne, Indiana.

Indiana & Michigan Power Company, the generating subsidiary of the Company, was formed in 1971 to own, complete the construction of, and operate the Donald C. Cook Nuclear Plant (the Nuclear Plant). Unit No. 1 of the Nuclear Plant was placed in commercial operation on August 23, 1975. Unit No. 2 was placed in commercial operation on July 1, 1978. The subsidiary sells all of the plant's generation to the parent for distribution to the latter's customers.

The Company serves 231 communities and approximately 437,000 customers in a 7,740-square-mile area of northern and eastern Indiana and a portion of southwestern Michigan. This area has an estimated population of 1,566,000. Among the principal industries served are manufacturers of automobiles, trucks, automotive parts, aircraft parts, steel, ferrous and nonferrous castings, farm machinery, machine tools, electric motors, electric transformers, electric wire and cable, glass, textiles, rubber products, food products and electronic components. In addition, the Company supplies wholesale electric power to other electric utilities, municipalities, and cooperatives.

The Company's generating plants and important load centers are interconnected by a high-voltage transmission network. This network in turn is interconnected either directly or indirectly with the following other AEP System companies to form a single major integrated power system: Appalachian Power Company, Kentucky Power Company, Kingsport Power Company, Michigan Power Company, Ohio Power Company, and Wheeling Electric Company. The Company is also interconnected with the following other utilities: Central Illinois Public Service Company, The Cincinnati Gas & Electric Company, Consumers Power Company, Commonwealth Edison Company, Illinois Power Company, Indiana-Kentucky Electric Corporation (a subsidiary of Ohio Valley Electric Corporation), Indianapolis Power & Light Company, Northern Indiana Public Service Company, and Public Service Company of Indiana, Inc.

Consolidated Summary of Operations

	Year Ended December 31,				
	1978	1977	1976	1975	1974
	(In Thousands)				
OPERATING REVENUES—ELECTRIC	<u>\$603,480</u>	<u>\$512,824</u>	<u>\$416,193</u>	<u>\$363,355</u>	<u>\$287,606</u>
OPERATING EXPENSES:					
Operation:					
Fuel for Electric Generation	125,277	74,052	70,127	55,775	55,216
Purchased and Interchange Power (Net) ...	116,308	144,833	126,712	121,194	111,161
Other	60,001	44,706	40,251	37,800	27,959
Maintenance	32,724	28,452	20,140	17,078	17,747
Depreciation	59,844	48,824	47,852	32,734	24,853
Taxes, Other Than Income Taxes	26,432	23,408	18,920	14,015	10,956
Federal and State Income Taxes	23,060	18,149	(8,625)	6,026	(3,086)
Total Operating Expenses	<u>443,646</u>	<u>382,424</u>	<u>315,377</u>	<u>284,622</u>	<u>244,806</u>
OPERATING INCOME	<u>159,834</u>	<u>130,400</u>	<u>100,816</u>	<u>78,733</u>	<u>42,800</u>
OTHER INCOME AND DEDUCTIONS:					
Allowance for Funds Used During Construction	—	—	28,874(a)	45,482(a)	59,454(a)
Allowance for Other Funds Used During Construction	27,974	26,889	—	—	—
Miscellaneous Nonoperating Income Less Deductions	1,040	952	718	135	1,537
Total Other Income and Deductions	<u>29,014</u>	<u>27,841</u>	<u>29,592</u>	<u>45,617</u>	<u>60,991</u>
INCOME BEFORE INTEREST CHARGES	<u>188,848</u>	<u>158,241</u>	<u>130,408</u>	<u>124,350</u>	<u>103,791</u>
INTEREST CHARGES:					
Total Interest Charges	96,648	80,772	76,534	70,822	70,388
Allowance for Borrowed Funds Used During Construction (Credit)	(22,627)	(19,651)	—	—	—
Net Interest Charges	<u>74,021</u>	<u>61,121</u>	<u>76,534</u>	<u>70,822</u>	<u>70,388</u>
CONSOLIDATED INCOME BEFORE CUMULATIVE EFFECT OF ACCOUNTING CHANGES	<u>114,827</u>	<u>97,120</u>	<u>53,874</u>	<u>53,528</u>	<u>33,403</u>
NON-RECURRING CUMULATIVE EFFECT OF ACCOUNTING CHANGES (Net of \$603,000 Applicable Taxes)	—	—	—	—	8,151
CONSOLIDATED NET INCOME	<u>\$114,827</u>	<u>\$ 97,120</u>	<u>\$ 53,874</u>	<u>\$ 53,528</u>	<u>\$ 41,554</u>

(a) Not reclassified into debt and equity components since allocation based on then existing capital structure would not necessarily be comparable to allocation under the FERC formula used after 1976.

Management's Comments on Consolidated Summary of Operations

The amounts shown in the Consolidated Summary of Operations and discussed below reflect only the results of past operations and are not intended as any representation as to the results of operations for any future period. Reference is made to the consolidated financial statements, related notes, and Operating Statistics and Balance Sheet Data for additional information concerning results of operations.

Operating Revenues—Electric

Electric operating revenues increased by \$96,631,000 (23%) in 1977 over 1976 and by \$90,656,000 (18%) in 1978 over 1977. Factors associated with the increases and related estimated amounts are as follows:

	Increase (Decrease)	
	1977 vs. 1976	1978 vs. 1977
	(In Millions)	
Base Rates and Fuel Cost Adjustments	\$109.3	\$ 53.8
Sales Volume	(21.2)	51.1
Sales Mix	8.2	(14.2)
Other Operating Revenues	0.3	—
Overall Increase ...	<u>\$ 96.6</u>	<u>\$ 90.7</u>

The increase in operating revenues in 1977 over 1976 was primarily attributable to rate increases placed in effect during 1976 and 1977 and to the recovery of increased fuel costs pursuant to the Company's fuel-adjustment clauses. Growth in operating revenues during 1977 was limited due to a 17% decrease in kilowatt-hour sales for resale. The increase in operating revenues in 1978 over 1977 reflected a 29% increase in kilowatt-hour sales for resale, the recovery of increased fuel costs, and rate increases placed in effect during 1977 and 1978. Conservation measures by some customers have tended to limit the growth of operating revenues in both 1977 and 1978.

Operating Expenses

Fuel for electric generation increased in 1977 over 1976 by \$3,925,000 (6%) and in 1978 over 1977 by \$51,225,000 (69%). Factors relating to these increases and the related estimated amounts are shown below:

	Increase (Decrease)			
	1977 vs. 1976			
	(In Millions)			
	Coal	Oil	Nuclear	Total
Cost of Fuel Consumed ..	\$ 5.1	\$ 4.1	\$ 2.4	\$11.6
Generation Level and Fuel Mix	(2.8)	1.0	(5.9)	(7.7)
Overall Increase (Decrease)	<u>\$ 2.3</u>	<u>\$ 5.1</u>	<u>\$(3.5)</u>	<u>\$ 3.9</u>
	1978 vs. 1977			
	(In Millions)			
	Coal	Oil	Nuclear	Total
Cost of Fuel Consumed ..	\$23.7	\$ 4.4	\$ 3.3	\$31.4
Generation Level and Fuel Mix	(2.2)	5.7	16.3	19.8
Overall Increase	<u>\$21.5</u>	<u>\$10.1</u>	<u>\$19.6</u>	<u>\$51.2</u>

The cost of fossil fuel consumed increased significantly in 1977 and 1978. The increase in 1977 was affected by there having been a refund of approximately \$4,000,000 to the Company in settlement of litigation with a supplier of fuel oil. (Such amount was recorded as a reduction to fuel for electric generation for 1976 and is reflected in the increase shown above in the cost of oil in 1977 from 1976.) A decrease in the quantity of nuclear fuel consumed in 1977 was related to the planned outage of Unit No. 1 of the Nuclear Plant for refueling. The increase in 1978 also reflected the placing of Unit No. 2 of the Nuclear Plant in commercial operation during July. The utilization of the relatively more expensive fuel oil (to conserve coal supplies) to generate electricity during the coal miners' strike which ended in March 1978 contributed to the increase in 1978 over 1977.

The purchased and interchange power increase of \$18,121,000 (14%) in 1977 and decrease of \$28,525,000 (20%) in 1978 primarily reflect the utilization of the Nuclear Plant as described above.

Other operation expense increased by \$15,295,000 (34%) in 1978 over 1977 mainly due to higher costs of labor, materials, supplies, and services, and was also affected by test generation prior to, and increased generation due to, placing of Unit No. 2 of the Nuclear Plant into commercial operation.

The increase in maintenance expense in 1977 over 1976 of \$8,312,000 (41%) was associated with cer-

MANAGEMENT'S COMMENTS ON CONSOLIDATED SUMMARY OF OPERATIONS (Concluded)

tain increased maintenance activity in 1977 which had previously been deferred and with higher labor cost and increased costs of materials, supplies, and services as regards power production maintenance. Maintenance expense increased by \$4,272,000 (15%) in 1978 over 1977 largely because of increasing cost levels and increased power plant, transmission and distribution maintenance activities.

The increase in depreciation expense in 1978 over 1977 of \$11,020,000 (23%) was chiefly due to the placing of Unit No. 2 of the Nuclear Plant and certain environmental protection facilities at the Company's Tanners Creek Plant in commercial operation.

Taxes, other than income taxes increased by \$4,488,000 (24%) in 1977. This was due to increases in utility plant in service and the completion in 1976 of the amortization (approximating \$3,000,000 for that year) of certain deferred credits associated with property taxes which had been deferred pursuant to regulatory authorization. The increase in taxes, other than income taxes in 1978 over 1977 of \$3,024,000 (13%) was largely attributable to increased Indiana Property Tax resulting from greater assessed valuation of property, increased Indiana Gross Income Tax at-

tributable to increased applicable revenues, and to Michigan Single Business Tax pertaining to the Generating Subsidiary.

Information concerning Federal income taxes (including a reconciliation of actual Federal income taxes to such taxes computed at statutory rates) is shown in Note 3 of Notes to Consolidated Financial statements.

Allowance for Funds Used During Construction

The allowance for funds used during construction (AFUDC), including the portion shown as a credit to interest charges, increased by \$17,666,000 (61%) in 1977. This increase was related to an increased amount invested in construction (including Unit No. 2 of the Nuclear Plant and precipitator installation projects at two of the Company's plants) and to the effect of the Generating Subsidiary's compounding AFUDC beginning in 1977.

Interest Charges

In 1978, total interest charges increased by \$15,876,000 (20%) over 1977; this was related to additional long-term debt outstanding.

Auditors' Opinion

To the Shareowners and the Board of Directors of
Indiana & Michigan Electric Company

We have examined the balance sheets of Indiana & Michigan Electric Company and its generating subsidiary, Indiana & Michigan Power Company, consolidated, as of December 31, 1978 and 1977 and the related statements of consolidated income, retained earnings and sources of funds for plant and property additions for the respective years then ended. Our examinations were made in accordance with generally accepted auditing standards and, accordingly, included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances.

As discussed in paragraphs three and five of Note 2 of Notes to Consolidated Financial Statements, the Company is collecting certain wholesale revenues subject to possible refund and has been incurring charges for interchange power subject to refund by its affiliated interchange power suppliers. An initial decision in the interchange power proceeding in February 1978, could, if sustained, result in substantial refunds to the Company. In addition, the Company is involved in antitrust matters discussed in paragraphs three and five of Note 10 of Notes to Consolidated Financial Statements.

In our opinion, subject to the effect on the financial statements identified above of such adjustments, if any, as might have been required had the outcome of the rate and antitrust matters referred to in the preceding paragraph been known, such financial statements present fairly the financial position of the above companies, consolidated, as of December 31, 1978 and 1977 and the results of their operations and their sources of funds for plant and property additions for the years then ended, in conformity with generally accepted accounting principles applied on a consistent basis.

Deloitte Haskins & Sells

New York, New York
February 19, 1979 (March 2, 1979
as to paragraph five of Note 10 of Notes
to Consolidated Financial Statements)

Consolidated Statement of Income

	Year Ended December 31,	
	1978	1977
	(In Thousands)	
OPERATING REVENUES—ELECTRIC (Notes 1 and 2)	\$603,480	\$512,824
OPERATING EXPENSES:		
Operation:		
Fuel for Electric Generation	125,277	74,052
Purchased and Interchange Power (Net) (Notes 2 and 9)	116,308	144,833
Other	60,001	44,706
Maintenance (Note 1)	32,724	28,452
Depreciation (Note 1)	59,844	48,824
Taxes, Other Than Income Taxes (Note 9)	26,432	23,408
State Income Taxes	(378)	704
Federal Income Taxes (Notes 1 and 3)	23,438	17,445
Total Operating Expenses	443,646	382,424
OPERATING INCOME	159,834	130,400
OTHER INCOME AND DEDUCTIONS (Notes 1 and 3):		
Allowance for Other Funds Used During Construction	27,974	26,889
Miscellaneous Nonoperating Income Less Deductions	1,040	952
Total Other Income and Deductions	29,014	27,841
INCOME BEFORE INTEREST CHARGES	188,848	158,241
INTEREST CHARGES:		
Interest on Long-term Debt	89,397	73,188
Interest on Short-term Debt	5,964	6,697
Miscellaneous Interest Charges (Note 1)	1,287	887
Total Interest Charges	96,648	80,772
Allowance for Borrowed Funds Used During Construction (Credit) (Note 1)	(22,627)	(19,651)
Net Interest Charges	74,021	61,121
CONSOLIDATED NET INCOME	\$114,827	\$ 97,120

See Notes to Consolidated Financial Statements.

Consolidated Balance Sheet

	December 31,	
	1978	1977
	(In Thousands)	
ASSETS AND OTHER DEBITS		
ELECTRIC UTILITY PLANT (Note 1):		
Production	\$1,345,070	\$ 864,902
Transmission	421,644	401,562
Distribution	257,186	244,103
General and Miscellaneous (includes Nuclear Fuel)	68,209	40,965
Construction Work in Progress	305,136	555,500
Total Electric Utility Plant	2,397,245	2,107,032
Less Accumulated Provision for Depreciation	410,520	358,826
Electric Utility Plant, Less Provision	1,986,725	1,748,206
OTHER PROPERTY AND INVESTMENTS (Notes 1 and 4)	170,299	137,421
CURRENT ASSETS:		
Cash (Note 8)	21,264	54,735
Special Deposits and Working Funds	6,750	24,065
Temporary Cash Investments (at cost, which approximates market)	—	8,494
Accounts Receivable:		
Customers	46,277	38,052
Associated Companies	7,511	9,382
Miscellaneous	4,498	4,968
Accumulated Provision for Uncollectible Accounts	(299)	(221)
Materials and Supplies (at average cost or less):		
Construction and Operation Materials and Supplies	12,783	11,468
Fuel	16,112	17,320
Accrued Utility Revenues	13,811	18,149
Prepayments and Other Current Assets	3,467	4,322
Total Current Assets	132,174	190,734
DEFERRED DEBITS:		
Unamortized Debt Expense (Note 1)	3,143	2,172
Property Taxes	1,422	1,450
Deferred Collection of Fuel Costs (Note 2)	1,584	1,655
Other Work in Progress	9,010	4,780
Other Deferred Debits	45,606	36,521
Total Deferred Debits	60,765	46,578
Total	\$2,349,963	\$2,122,939

See Notes to Consolidated Financial Statements.

LIABILITIES AND OTHER CREDITS

December 31,
1978 1977
(In Thousands)

CAPITALIZATION:

Common Stock—No Par Value (Note 5):

Authorized—2,500,000 Shares

Outstanding—1,400,000 Shares	\$ 56,584	\$ 56,584
Premium on Capital Stock (Note 5)	381	381
Other Paid-in Capital (Note 5)	470,228	410,228
Retained Earnings (Note 6)	136,829	104,566
Total Common Shareowner's Equity	664,022	571,759
Cumulative Preferred Stock (Note 7)	227,000	187,000
Long-term Debt (less portion due within one year) (Note 8) ...	1,043,090	977,062
Total Capitalization (less long-term debt due within one year)	<u>1,934,112</u>	<u>1,735,821</u>

CURRENT LIABILITIES:

Long-term Debt Due Within One Year (Note 8)	7,536	61,421
Short-term Debt (Note 8):		
Notes Payable to Banks	69,490	49,650
Commercial Paper	55,450	52,200
Accounts Payable:		
General	50,460	19,650
Associated Companies	15,305	16,306
Dividends Declared:		
Common Stock	14,252	11,360
Cumulative Preferred Stock	4,754	3,854
Customer Deposits	1,909	1,739
Taxes Accrued	20,005	18,804
Interest Accrued	18,338	19,041
Other Current Liabilities	16,439	16,653
Total Current Liabilities	<u>273,938</u>	<u>270,678</u>

COMMITMENTS AND CONTINGENCIES (Note 10)

DEFERRED CREDITS AND OPERATING RESERVES:

Deferred Income Taxes (Note 1)	120,921	102,143
Deferred Investment Tax Credits (Notes 1 and 3)	8,503	10,785
Other Deferred Credits and Operating Reserves	12,489	3,512
Total Deferred Credits and Operating Reserves	<u>141,913</u>	<u>116,440</u>
Total	<u>\$2,349,963</u>	<u>\$2,122,939</u>

Consolidated Statement of Sources of Funds for Plant and Property Additions

	Year Ended December 31,	
	1978	1977
	(In Thousands)	
FUNDS FROM OPERATIONS:		
Consolidated Net Income	\$114,827	\$ 97,120
Principal Non-fund Charges (Credits) to Income:		
Depreciation	59,853	48,837
Provision for Deferred Income Taxes (Net)	18,779	13,535
Deferred Investment Tax Credits (Net)	3,423	5,038
Allowance for Other Funds Used During Construction	(27,974)	(26,889)
Other (Net)	506	72
Total Funds from Operations	<u>169,414</u>	<u>137,713</u>
FUNDS FROM FINANCINGS:		
Issuances and Contributions:		
Long-term Debt	369,839	135,391
Cumulative Preferred Stock	38,486	38,120
Capital Contributions from Parent Company	60,000	58,000
Short-term Debt (Net)	23,090	—
Total	<u>491,415</u>	<u>231,511</u>
Less—Retirements:		
Long-term Debt	357,877	10,873
Short-term Debt (Net)	—	46,163
Net Funds from Financings	<u>133,538</u>	<u>174,475</u>
DIVIDENDS ON COMMON STOCK	(62,692)	(52,920)
DIVIDENDS ON CUMULATIVE PREFERRED STOCK	(18,357)	(14,041)
SALES OF PROPERTY	42,416	97,311
OTHER CHANGES (NET)	(13,675)	(4,523)
DECREASE (INCREASE) IN WORKING CAPITAL (Excluding Short-term Debt and Long-term Debt Due Within One Year) (a) ...	<u>92,615</u>	<u>(61,061)</u>
Total	<u>\$343,259</u>	<u>\$276,954</u>
PLANT AND PROPERTY ADDITIONS:		
Gross Additions to Utility Plant	\$340,209	\$272,433
Gross Other Additions	31,024	31,410
Total Gross Additions	<u>371,233</u>	<u>303,843</u>
Allowance for Other Funds Used During Construction	(27,974)	(26,889)
Total	<u>\$343,259</u>	<u>\$276,954</u>
(a) Represented by decrease (increase) as follows:		
Cash and Cash Items	\$ 59,280	\$ (30,020)
Accounts Receivable	(5,806)	(3,534)
Materials and Supplies	(107)	(5,851)
Accounts Payable	29,809	(11,096)
Taxes Accrued	1,201	(1,087)
Other (Net)	8,238	(9,473)
	<u>\$ 92,615</u>	<u>\$ (61,061)</u>

See Notes to Consolidated Financial Statements.

Consolidated Statement of Retained Earnings

	December 31,	
	1978	1977
	(In Thousands)	
Balance at Beginning of Year	\$104,566	\$ 76,286
Consolidated Net Income	114,827	97,120
Total	<u>219,393</u>	<u>173,406</u>
Deductions:		
Cash Dividends Declared:		
Common Stock	62,692	52,920
Cumulative Preferred Stock:		
4½ % Series	495	495
4.56% Series	273	273
4.12% Series	165	165
7.08% Series	2,124	2,124
7.76% Series	2,716	2,716
8.68% Series	2,604	2,604
12 % Series	3,600	3,600
\$2.15 Series	3,440	2,064
\$2.25 Series	2,940	—
Total Cash Dividends Declared	81,049	66,961
Capital Stock Expense	1,515	1,879
Total Deductions	<u>82,564</u>	<u>68,840</u>
Balance at End of Year (Note 6)	<u>\$136,829</u>	<u>\$104,566</u>

See Notes to Consolidated Financial Statements.

Notes to Consolidated Financial Statements

1. Significant Accounting Policies:

The common stock of the Company is wholly owned by American Electric Power Company, Inc. (AEP). The consolidated financial statements include the accounts of the Company and its wholly owned subsidiary Indiana & Michigan Power Company (the Generating Subsidiary). The Generating Subsidiary was formed to own, complete construction of and operate the Donald C. Cook Nuclear Plant, the first unit of which has been in commercial operation since 1975 and the second unit of which was placed in commercial operation during July 1978. Significant intercompany items have been eliminated in consolidation. A minor inactive subsidiary has not been consolidated.

The accounting and rates of the Company and the Generating Subsidiary are subject in certain respects to the requirements of state regulatory bodies and in certain respects to the requirements of the Federal Energy Regulatory Commission (FERC). The consolidated financial statements have been prepared, with full reservation of legal rights, on the basis of the accounts which are maintained for FERC purposes.

Utility Plant, Other Property and Investments and Depreciation

Electric utility plant is stated at original cost. Generally, the plant of the Company and the Generating Subsidiary is subject to first mortgage liens.

The companies capitalize, as a construction cost, an allowance for funds used during construction, an item not representing cash income, which is defined in the applicable regulatory systems of accounts as the net cost of borrowed funds used for construction purposes and a reasonable rate on other funds when so used. The respective composite rates used by the Company and the Generating Subsidiary were increased to 10.5% and 10.2%, respectively, during 1978 (effective January 1) from 8.5% used by both companies in 1977, (applied by the Company on an annual basis and by the Generating Subsidiary on a semiannual compound basis).

The companies provide for depreciation on a straight-line basis over the estimated useful lives of the property. The current provisions are determined largely with the use of functional composite rates as follows:

Functional Class of Property	Composite Annual Rate
Production:	
Steam—Nuclear	4.0%
Steam—Fossil-fired	3.1%
Transmission	2.9%
Distribution	3.3%
General	3.5%

Income is charged with the costs of labor, materials, supervision, and other costs incurred in maintaining the properties. Property accounts are charged with costs of betterments and major replacements of property, and the accumulated provisions for depreciation are charged with retirements, together with removal costs less salvage.

Nonutility property, other property investments, and other investments are generally stated at cost.

Income Taxes

Deferred Federal income taxes, reduced where applicable by investment tax credits, are provided by the Company and the Generating Subsidiary generally to the extent that such amounts are allowed for rate-making purposes. On October 1, 1978, the Company and its Generating Subsidiary expanded deferred tax accounting to additional timing differences pursuant to an order of the Public Service Commission of Indiana.

The Company and the Generating Subsidiary practice deferral accounting for the effect of tax reductions resulting from the application of investment tax credits to provisions for current and certain deferred Federal income taxes. The deferred investment tax credit applicable to current Federal income taxes payable is amortized over 30 years.

Pension Plan

The Company and the Generating Subsidiary participate with other companies in the AEP System in a trustee plan to provide pensions for all employees, subject to certain eligibility requirements. The plan was previously contributory on the part of employees, but as of January 1, 1978, required employee contributions were eliminated as to substantially all employees. The pension plan conforms to the Employee Retirement Income Security Act of 1974 (ERISA).

Pension costs for the years ended December 31, 1978 and 1977 were approximately \$2,624,000 and \$2,170,000, respectively, representing the cost of currently accruing benefits. There were no unfunded prior service costs as of December 31, 1978. Effective January 1, 1979, benefits of the plan were modified. The change resulted in unfunded prior service costs of approximately \$1,970,000, which will be amortized over 30 years. The plan may be modified or terminated at any time, subject to limitations of labor agreements.

Employees Savings Plan

The Company and the Generating Subsidiary participate with other AEP System companies in a trustee savings plan which became effective January 1, 1978 and is available to employees who have met eligibility requirements. The savings plan conforms to the applicable provisions of ERISA. Each employer contributes

to the plan an amount equal to 50% of its employee-participants' contributions up to 6% of their regular compensation. Benefits to participating employees are based solely upon amounts contributed to the participants' accounts. By its nature the plan is fully funded at all times. The cost of the plan for the year ended December 31, 1978 totaled \$607,000.

Other

The Company accrues unbilled revenues for services rendered subsequent to the last billing cycle through month-end.

Miscellaneous nonoperating income for the years ended December 31, 1978 and 1977 includes gains amounting to \$261,000 and \$306,000, respectively, on certain long-term debt reacquired.

Debt discount or premium and debt expense are being amortized over the lives of the related debt issues and the amortization thereof is included within miscellaneous interest charges.

2. Operating Revenues and Operating Expenses:

The Company has collected retail revenues under final orders of the Public Service Commission of Indiana which became effective in February 1977 and September 1978. The 1977 order has been appealed to a court of appeals and certain parties have initiated proceedings looking toward an appeal from the 1978 order.

In September 1978, FERC ordered that the Company refund approximately \$3,000,000 to a municipal customer. The Company recorded the refund in the third quarter of 1978. The effect of such refund on prior periods was not material.

Revenues collected by the Company from wholesale rate increases placed into effect subject to possible refund (exclusive of the amount refunded as described above) are estimated as follows:

	(In Thousands)
1978	\$20,777
1977	16,439
Prior to 1977	5,224
Total	<u>\$42,440</u>

See Note 10 for information with respect to an anti-trust decision enjoining the Company from charging certain wholesale rates.

Commencing in June 1975, operating expenses include the effect of changes in rates charged for interchange power transactions between the Company and other companies in the AEP System. The effect of such changes was to increase the charges to the Company, subject to possible refund by its interchange power suppliers, by the following estimated amounts:

	(In Thousands)
1978	\$ 24,981
1977	27,968
Prior to 1977	50,368
Total	<u>\$103,317</u>

On February 23, 1978, an administrative law judge of FERC issued an initial decision ordering one of the affiliated interchange power suppliers to make certain refunds, after recomputing interchange charges for the period subsequent to June 1975 on the basis of the interconnection agreement in effect prior to that date, but excluding from such calculations as member capacity, in the case of the Company, the capacity owned by the Generating Subsidiary and, in the case of another member of the System, the capacity owned by its generating subsidiary. If the change is finally ordered by FERC, the Company could become entitled to refunds in a substantial amount. Certain intervenors have urged that changes be made in the interconnection agreement, which would have the opposite effect, increasing the amounts payable by the Company. The AEP System subsidiaries, including the Company, have filed a brief which urges that the action of the administrative law judge be revised so as to sustain the original amounts charged, but cannot predict the final outcome of the proceeding or the effect thereof on the Company.

Operating revenues derived from domestic governmental entities represent approximately 8% and 10% of total operating revenues for 1978 and 1977, respectively. Operating revenues derived from a certain wholesale customer represent approximately 12% and 7% of total operating revenues for 1978 and 1977, respectively.

In 1978 the Company received approval of the Public Service Commission of Indiana to collect, over a five-year period ending in 1983, substantially all of its deferred fuel costs.

3. Federal Income Taxes:

The details of Federal income taxes are as follows:

	Year Ended December 31,	
	1978	1977
	(In Thousands)	
Charged (Credited) to Operating Expenses:		
Current Federal Income Taxes (Net)	\$1,357	\$(1,128)
Deferred Federal Income Taxes (Net)	18,658	13,535
Deferred Investment Tax Credits (Net)	3,423	5,038
Total	23,438	17,445
Charged to Other Income and Deductions	936(a)	537
Total Federal Income Taxes	<u>\$24,374</u>	<u>\$17,982</u>

(a) Includes deferred income taxes of \$121,000.

NOTES TO CONSOLIDATED FINANCIAL STATEMENTS (Continued)

The consolidated effective Federal income tax rates were less than the statutory rates for the years 1978 and 1977. The following is a reconciliation of the differences between the amount of Federal income tax expense reported in the Consolidated Statement of Income and the amount of Federal income taxes computed by multiplying consolidated net income before Federal income taxes by the statutory tax rate.

	Year Ended December 31,	
	1978	1977
	(In Thousands)	
Consolidated Net Income	\$114,827	\$ 97,120
Federal Income Taxes	24,374	17,982
Pre-Tax Book Income	<u>\$139,201</u>	<u>\$115,102</u>
Federal Income Tax on Pre-Tax Book Income at Statutory Rate of 48%	\$ 66,816	\$ 55,249
Increase (Decrease) in Federal Income Taxes Resulting from:		
Excess of Tax over Book Depreciation	(19,691)	(16,080)
Allowance for Funds Used During Construction and Items Capitalized on the Books but Deducted for Tax Purposes	(25,853)	(24,005)
Mine Development and Exploration Expense	(4,680)	(1,962)
Provision for Revenue Refunds	(888)	(2,912)
Amortization of Pollution Control Facilities	(4,080)	(1,609)
Miscellaneous Items	109	(5,633)
Federal Income Tax on Current-Year Taxable Income (Separate-Return Basis)	11,733	3,048
Reduction Due to System Consolidation	(11,733)	(3,048)
Minimum Tax on Preference Items	650	18
Currently Payable	650	18
Adjustments of Prior-Year Accruals (Net)	(276)	(774)
Adjustments for Tax Losses (a):		
Federal Income Taxes	7,503	68
Investment Tax Credit	(5,705)	97
Current Federal Income Taxes (Net)	<u>2,172</u>	<u>(591)</u>
Deferred Federal Income Taxes (Net of Amortization) Resulting from the Following Timing Differences:		
Depreciation (Liberalized and Asset Depreciation Range)	17,439	13,931
Unbilled Revenue	(1,221)	3,315
Accelerated Amortization of Emergency Facilities (Amortization of Prior-Year Provisions)	(1,848)	(1,882)
Provision for Revenue Refunds	—	2,213
Other	2,188	1,154
Investment Tax Credit Applicable to Deferred Federal Income Taxes on Certain Timing Differences	<u>2,221</u>	<u>(5,196)</u>
Deferred Federal Income Taxes (Net)	<u>18,779</u>	<u>13,535</u>
Deferred Investment Tax Credits (Net)	<u>3,423(c)</u>	<u>5,038</u>
Total Federal Income Taxes	<u>\$ 24,374</u>	<u>\$ 17,982</u>

- (a) The AEP System allocates Federal income taxes currently payable in accordance with SEC regulations, which require that the benefit of tax losses be allocated to the AEP System companies with taxable income. The benefits of these tax losses, without affecting taxes payable, are reallocated to the AEP System companies giving rise to such losses, as it is expected that these losses would be usable in subsequent years to reduce taxes payable of the loss companies.

- (b) In accordance with an order of the SEC under the Public Utility Holding Company Act of 1935, a tax loss of the Generating Subsidiary is to be first applied to reduce the taxable income of the Company and any unused amount is to be allocated among the other System companies included in the consolidated Federal income tax return, but with the provision that any losses so allocated to other System companies shall be reallocated to the Company if usable by it in subsequent years. The effect of tax losses allocated to other companies would be included in the reallocation referred to in (a) above.
- (c) The System consolidated Federal income tax return for 1977, filed in 1978, showed a taxable income which was less than that estimated for the year-end accrual. The decrease was principally attributable to additional percentage repair allowance deductions of the Company and affiliated companies and mine development expense deductions of the Company claimed over the estimated amounts utilized in preparing the 1977 year-end accrual. These differences had no significant effect on the amount of income taxes payable for 1977 because of the effect of investment tax credits; however, total System Federal income taxes for 1977 would have been reduced due to the related reversal of deferred investment tax credits. The increase in income (\$3,194,000) resulting from these differences in estimates was recorded by the Company in the third quarter of 1978.

The Company joins in the filing of a consolidated Federal income tax return with its affiliated companies in the AEP System. Unused System investment tax credits at December 31, 1978 aggregated approximately \$201,000,000, of which approximately \$21,300,000 may be carried forward through 1981, \$52,800,000 through 1982, \$20,500,000 through 1983, \$27,400,000 through 1984, and \$79,000,000 through 1985. Of these amounts, approximately \$26,000,000 had been applied as a reduction of deferred income taxes prior to December 31, 1978 and will not be reflected in net income when realized in future years except as affected by changes in deferred income taxes.

The System consolidated Federal income tax returns for the years prior to 1965 have been settled. The returns for the years 1965 through 1969 together with certain unrecorded refund claims relating to the years 1965, 1966 and 1967 are currently being settled on the basis of a net refund for the period, the amount of which the System companies deem immaterial. The returns for the years 1970 through 1973 have been reviewed by the Internal Revenue Service and additional taxes for those years have been proposed, some of which the System companies have protested. In the opinion of the System companies, adequate provision has been made for such additional taxes.

4. Other Property and Investments:

The following is an analysis of other property and investments:

	Year Ended December 31,	
	1978	1977
(In Thousands)		
Nonutility Property and Other Property Investments:		
Western Coal Lands Acquired as Source of Low-Sulfur Fuel ...	\$149,713	\$120,799
Other Coal Properties and Fuel- Handling Facilities	4,946	3,692
Miscellaneous (Net)	15,495	12,674
Subtotal	170,154	137,165
Ohio Valley Electric Corporation Sub- ordinated Notes	—	56
Other Investments	145	200
Total Other Property and Investments	\$170,299	\$137,421

5. Common Stock, Premium on Capital Stock, and Other Paid-in Capital:

There were no common stock transactions and no transactions affecting premium on capital stock during the years 1978 and 1977. The Company received from its parent cash capital contributions of \$60,000,000 in 1978 and \$58,000,000 in 1977; such contributions were credited to other paid-in capital.

6. Retained Earnings:

Various restrictions on the use of retained earnings for cash dividends on common stock and other purposes are contained in or result from covenants in mortgage indentures, debenture and bank loan agreements, charter provisions, and orders of regulatory authorities. Approximately \$48,500,000 at December 31, 1978 was so restricted.

NOTES TO CONSOLIDATED FINANCIAL STATEMENTS (Continued)

7. Cumulative Preferred Stock

The following is an analysis of cumulative preferred stock:

Series	Current Call Price(a)	Redemption Restricted Prior to	Par Value	Shares Outstanding	Amount	
					December 31,	
					1978	1977
(In Thousands)						
4 1/8%	\$106.125		\$100	120,000	\$ 12,000	\$ 12,000
4.56%	102.000		100	60,000	6,000	6,000
4.12%	102.728		100	40,000	4,000	4,000
7.08%	106.450		100	300,000	30,000	30,000
7.76%	107.320		100	350,000	35,000	35,000
8.68%	107.440		100	300,000	30,000	30,000
12 %	112.000(b)	9/1/80	100	300,000	30,000	30,000
\$2.15	27.150	5/1/82	25	1,600,000	40,000	40,000
\$2.25	27.250	3/1/83	25	1,600,000	40,000	—
Total Cumulative Preferred Stock					\$227,000	\$187,000

(a) Callable at the option of the Company, at the price indicated plus accrued dividends. The involuntary liquidation preference is par value.

(b) A sinking fund for the 12% series requires the Company to provide, on or before October 1 of each year, beginning in 1980, for the purchase, or redemption at \$100 a share, of 15,000 shares of such series. The Company has the right, on each sinking fund date, to redeem an additional 15,000 shares. Unless all sinking fund provisions have been met, no distribution may be made on the common stock.

In 1976 shareowners authorized the issuance of up to 4,000,000 shares of \$25 par value cumulative preferred stock (which ranks equally with the \$100 par value cumulative preferred stock) and in 1978 increased the authorization to 7,200,000 shares. In 1977 the Company issued and sold 1,600,000 shares of the \$2.15 series and in 1978 the Company issued and sold 1,600,000 shares of the \$2.25 series.

At December 31, 1978, authorized shares of cumulative preferred stock were as follows:

Par Value	Shares Authorized
\$100	2,250,000
25	7,200,000

8. Long-term Debt, Short-term Debt, Lines of Credit, and Compensating Balances:

Long-term debt by major category was outstanding as follows (less portion due within one year):

	December 31,	
	1978	1977
(In Thousands)		
First Mortgage Bonds	\$ 832,286	\$482,826
Sinking Fund Debentures	24,083	25,260
Notes Payable to Banks, due 1980	82,000	360,000
Installment Purchase Contracts	99,841	99,750
Other Long-term Debt	4,880	9,226
Total (less portion due within one year)	<u>\$1,043,090</u>	<u>\$977,062</u>

First mortgage bonds outstanding were as follows:

Series	Due	December 31,	
		1978	1977
		(In Thousands)	
6½% 1978(a)		\$ —	\$ 30,000
3 % 1978(b)		—	24,173
2¾% 1980		18,015	18,015
3¼% 1982		16,046	16,046
10¼% 1982		70,000	70,000
3⅝% 1983		13,762	13,762
11 % 1983		60,000	60,000
3⅛% 1984		15,082	15,082
10⅞% 1984(c)(d)(e)		66,000	70,500
10 % 1985(e)		13,500	14,250
3⅞% 1988		22,974	22,974
4¾% 1988		17,557	17,557
4⅝% 1993		42,902	42,902

Series	Due	December 31,	
		1978	1977
(In Thousands)			
7 %	1998	\$ 35,000	\$ 35,000
8¾ %	2000	50,000	50,000
8¾ %	2003	40,000	40,000
9½ %	2003(c)	255,000	—
9½ %	2008	100,000	—
Unamortized Debt			
Discount—Net		(552)	(262)
		835,286	539,999
Less Portion due Within One Year ..		3,000	57,173
Total		\$832,286	\$482,826

(a) Retired February 1, 1978.

(b) Retired September 1, 1978.

(c) Guaranteed by American Electric Power Company, Inc.

(d) These bonds are obligations of the Generating Subsidiary. The unamortized discount amounted to \$189,000 and \$221,000 at December 31, 1978 and 1977, respectively.

(e) Sinking fund payments are required as follows:

10% series due 1985—\$750,000 annually on March 1.

10 1/8% series due 1984—\$2,250,000 annually on December 1, through 1983, with the noncumulative election to redeem an additional \$2,250,000 in each year.

9 1/2% series due 2003—\$11,500,000 annually on June 1, 1980 through 1991 and \$13,500,000 annually on June 1, 1992 through 2002 with the noncumulative option to redeem an additional amount in each of the specified years from a minimum of \$100,000 to a maximum equal to the scheduled requirement for each year, but with a maximum optional redemption, as to all years in the aggregate, of \$75,000,000.

In January 1979, the Company issued \$80,000,000 of 10 1/4% first mortgage bonds due in 1987. The

Generating Subsidiary has a delayed-delivery contract to sell an additional \$45,000,000 of its first mortgage bonds, 9½% Series due 2003, on March 1, 1979.

The indentures relating to the first mortgage bonds contain improvement, maintenance and replacement provisions requiring the deposit of cash or bonds with the trustee, or in lieu thereof, certification of unfunded property additions. The Company has elected to use unfunded property additions to meet these provisions in the past.

Sinking fund debentures of the Company outstanding were as follows:

	December 31,	
	1978	1977
	(In Thousands)	
5½% Due 1986	\$12,076	\$12,491
7¼% Due 1998	11,941	12,694
Unamortized Debt Premium	66	75
Total	<u>\$24,083</u>	<u>\$25,260</u>

Installment purchase contracts of the Company were as follows:

	December 31,	
	1978	1977
	(In Thousands)	
City of Lawrenceburg, Indiana:		
8½% Series due 2006	\$25,000	\$25,000
7% Series due 2006	40,000	40,000
6½% Series due 2006	12,000	12,000
City of Sullivan, Indiana:		
6½% Series due 2006	25,000	25,000
Unamortized Debt Discount	(2,159)	(2,250)
Total	<u>\$99,841</u>	<u>\$99,750</u>

Under the terms of certain installment purchase contracts, the Company is required to pay purchase price installments in amounts sufficient to enable the cities to pay interest on and the principal (at stated maturities and upon mandatory redemption) of related pollution control revenue bonds issued to finance the construction of pollution control facilities at the Company's Tanners Creek and Breed Plants.

Other long-term debt of the Company outstanding consisted of:

	December 31,	
	1978	1977
	(In Thousands)	
Coal reserve obligations—payable in equal annual installments through 1980 with interest at 8%	\$ 8,252	\$12,377
Notes payable—due 1978 through 1985, 6%-7%	902	934
Other	262	162
	<u>9,416</u>	<u>13,473</u>
Less portion due within one year	<u>4,536</u>	<u>4,247</u>
Total	<u>\$ 4,880</u>	<u>\$ 9,226</u>

Consolidated long-term debt outstanding at December 31, 1978 is due as follows:

	Principal Amount
	(In Thousands)
1979	\$ 7,536
1980	118,859
1981	15,032
1982	101,304
1983	89,035
Later Years	<u>721,505</u>
Total	<u>\$1,053,271</u>

At December 31, 1978 and 1977, the principal amounts of debentures reacquired in anticipation of sinking fund requirements were \$2,183,000 and \$1,815,000, respectively. The companies may make additional debenture or first mortgage bond sinking fund payments of up to \$3,050,000 annually (\$2,250,000 relating to Generating Subsidiary).

The interest rate on the long-term notes payable to banks (an average of 12.2% at December 31, 1978 and 8.4% at December 31, 1977) depends on the prime commercial rate plus a fractional percentage. The Generating Subsidiary has informal arrangements with the banks to maintain average compensating bank balances equal to approximately 15% of certain of the notes outstanding on an average basis or such smaller amount as the banks consider appropriate in view of other banking relationships or, in lieu thereof, to pay a fee on any draw-down of the compensating balances based on the approximate effective interest cost of the related notes, assuming the full compensating balances had been maintained: At December 31, 1978 and 1977, the compensating balances under the arrangements were approximately \$9,800,000 and \$34,100,000, respectively. The effective interest rate, representing the actual interest rates on the notes outstanding adjusted for the effect of the compensating balance requirements, averaged 13.9% at December 31, 1978 and was approximately 9.6% at December 31, 1977.

Short-term debt and interest rates thereon were as follows:

	1978	1977
	(Dollars in Thousands)	
Weighted average interest rates for debt outstanding at end of year:		
Notes Payable to Banks	10.9%	7.8%
Commercial Paper	11.2%	7.4%
Maximum amount of debt outstanding at any month-end during the year:		
Notes Payable to Banks	\$69,490	\$87,400
Commercial Paper	\$55,450	\$76,042

NOTES TO CONSOLIDATED FINANCIAL STATEMENTS (Continued)

	1978	1977
	(Dollars in Thousands)	
Weighted average interest rate of debt outstanding during the year (a):		
Notes Payable to Banks	9.4%	6.6%
Commercial Paper	9.1%	6.6%
Average amount of debt outstanding during the year:		
Notes Payable to Banks	\$31,862	\$39,457
Commercial Paper	\$36,211	\$58,716

(a) Average interest rates are determined by dividing interest expensed for the year by average month-end debt.

The Company had unused short-term bank lines of credit of approximately \$144,000,000 and \$208,000,000 at December 31, 1978 and 1977, respectively, under which notes could be issued with no maturity more than 270 days after date of issue. The available lines of credit are subject to withdrawal at the banks' option, and \$135,000,000 and \$200,000,000, respectively, of such lines are shared with other AEP System companies. In accordance with informal agreements with the banks, compensating balances of up to 10% or, in certain instances, equivalent fees are required to maintain the lines of credit, and, on any amounts actually borrowed, generally either additional compensating balances of up to 10% are maintained or adjustments in interest rates are made. Substantially all bank balances are maintained by the Company to compensate the banks for services and for both used and available lines of credit.

9. Supplemental Income Statement Information and Related-Party Transactions:

Electric operating revenues shown in the Consolidated Statement of Income include sales of energy to AEP System companies of approximately \$17,500,000 and \$14,500,000 for the years ended December 31, 1978 and 1977, respectively.

Operating expenses shown in the Consolidated Statement of Income include certain items not shown separately, as follows:

	Year Ended December 31,	
	1978	1977
	(In Thousands)	
Purchased Power (a)	\$ 6,241	\$ 2,965
Interchange Power (Net):		
AEP System Electric Utilities	80,043	140,957
Other Companies (b)	30,024	911
	<u>\$116,308</u>	<u>\$144,833</u>

	Year Ended December 31,	
	1978	1977
	(In Thousands)	
Taxes, Other Than Income Taxes:		
Real and Personal Property Taxes..	\$ 14,617	\$ 13,609
State Gross Sales, Excise and Franchise Taxes, and Miscellaneous State and Local Taxes	9,842	8,078
Social Security Taxes—Federal and State	1,973	1,721
	<u>\$ 26,432</u>	<u>\$ 23,408</u>

(a) Includes power purchased from OVEC of approximately \$1,558,000 in 1978 and \$476,000 in 1977.

(b) Includes interchange power sold to OVEC of approximately \$908,000 in 1978 and \$956,000 in 1977.

Charges to income for royalties and advertising are less than 1% of gross revenues in each case.

Sales and purchases of energy and interchange power transactions are regulated by the various commissions having jurisdiction.

American Electric Power Service Corporation provides certain services to the Company and the affiliated companies in the AEP System. The costs of the services are determined by the service company on a direct-charge basis to the extent practicable and on reasonable bases of proration for indirect costs. The charges for services are made on a cost basis but include no compensation for the use of equity capital, all of which is furnished to the service company by AEP. The service company is subject to the regulation of the Securities and Exchange Commission under the Public Utility Holding Company Act of 1935.

10. Commitments and Contingencies:

The construction budget of the Company and the Generating Subsidiary for the year 1979 is estimated at \$241,000,000 and, in connection therewith, commitments have been made.

The Company participates with its parent, two associated utility companies, several unaffiliated utility companies, and Ohio Valley Electric Corporation (OVEC) in supplying the U.S. Department of Energy (DOE) with the power requirements of its plant near Portsmouth, Ohio. The proceeds from the sales of power by OVEC are designed to be sufficient for OVEC to meet its operating expenses and fixed costs, including amortization of long-term debt capital (balance approximately \$43,300,000 as of December 31, 1978), over a period ending in 1982, and to provide for an annual return on its equity capital. The Company, as a participant, is entitled to receive from OVEC, and is obligated to pay for, 7.6% of the power not required by DOE. The power agreement terminates

in 1979 but DOE has notified OVEC of its desire to negotiate an extension to 1992.

In 1978, three court proceedings brought in recent years by certain municipalities in Indiana and Michigan, all wholesale customers of the Company, were combined into a single consolidated case in a U.S. District Court and a fourth action was commenced in the same court. A trial of the consolidated case was held and in January 1979 the court ruled for the plaintiffs that the Company, its parent, and American Electric Power Service Corporation have violated the antitrust laws, awarded the municipalities damages of approximately \$12,100,000 when trebled, placed limitations on the Company's putting into effect or charging wholesale rates to the plaintiffs and enjoined the Company from certain practices. The financial statements at December 31, 1978 do not include any provision for such damages. The companies are appealing the decision and provisions of the judgment awarding monetary damages have been stayed.

In another proceeding, the Company is awaiting decision on its appeal to FERC, filed in 1977, with respect to a ruling by an administrative law judge on a complaint made to the commission by the same group of municipalities. That complaint, alleging that the municipal electric systems had been threatened with termination of wholesale electric service, had earlier been upheld by the FERC judge.

In March 1979, two other municipal customers brought a separate action against the Company, its parent and the Service Corporation alleging violations of the antitrust laws and seeking damages of at least \$7,000,000 before trebling and other remedies. Certain issues in the complaint are similar to those tried in the consolidated case discussed in the second preceding paragraph.

As previously reported, the Securities and Exchange Commission (SEC) had commenced an investigation, through its staff, into certain aspects of the AEP System's operations, including its promotion of all-electric housing during the 1960's and the acquisition and operation of certain coal and transportation properties. The SEC staff had maintained that commission authorization should have been obtained for some of the transactions. The AEP System companies disagreed but did agree to a negotiated settlement in order to avoid long litigation with the SEC. As a result, the AEP System companies agreed to a consent order in a U. S. District Court in which they neither admitted nor denied the allegations. As part of the agreement, a special auditor was appointed to review intercompany charges and costs associated with the programs and

transactions involved in the investigation; the auditor's report was filed in December 1978. The AEP System companies are engaged in a continuing program for the orderly and economic divestment of a limited amount of real estate, acquired in connection with the housing and industrial development programs, that was subject to question.

In 1975, an investigation was commenced under the Federal Power Act concerning the reasonableness and prudence of the coal-purchasing policies and practices of members of the AEP System, the manner in which wholesale fuel-adjustment clauses are implemented by System members, and related matters. In 1978 the FERC staff issued a preliminary report which alleged overcharges of approximately \$10,000,000 on the part of the entire AEP System, of which only a relatively small portion relates to the Company's operations. The report also questioned certain aspects of the AEP System's fuel positions and policies. The AEP System companies are preparing a response to these allegations.

In 1976 a cable-television organization filed an anti-trust suit in a U.S. District Court alleging that the Company, with five telephone companies named as co-conspirators, had attempted to monopolize communications by terminating contracts and increasing charges for the rental of utility poles, and sought damages which when trebled would aggregate more than \$150,000,000. In early 1979, the court entered a judgment denying damages and injunctive relief.

The companies are subject to certain developing laws and regulations with respect to air and water quality, land use, and other environmental matters. While the companies are unable to predict the ultimate effect of such laws and regulations, it is possible that they may be required to pay penalties for failure to comply during certain periods or that compliance therewith may require the companies to incur substantial additional costs to modify or replace existing and proposed equipment and facilities.

Other highly complex litigation relates to the Donald C. Cook Nuclear Plant's fuel-supply contracts. Two contractors, United Nuclear Corporation and General Atomic Company (GAC), are variously obligated to supply uranium concentrates and six fabricated nuclear-fuel reloads to the Company. Each contractor claims, among other things, that it is not or may not be obligated to make deliveries of uranium concentrates or fabricated nuclear-fuel reloads and that it is entitled to a price higher than contracted. The Company received the first two reloads and assured delivery of the remaining four reloads through rights-reserved agreements with GAC, which were incorporated into injunctive

NOTES TO CONSOLIDATED FINANCIAL STATEMENTS (Concluded)

orders of the court. Under the agreements, pending the court's judgment and without prejudice to the ultimate rights of the parties, the reloads were to be supplied at a higher provisional cost to the Company. In 1978, a U.S. District Court entered judgment ordering GAC to pay the Company damages of approximately \$16,000,000 and to deliver the remaining reloads at the price specified in the contract. GAC has appealed the judgment. A stay of the monetary portion of the judgment has been granted, but motions to stay the specific-performance portion of the judgment have been denied.

The companies intend to apply to regulatory commissions to provide, through future increased rates, for the costs that will be incurred to store spent nuclear fuel and to decommission the Nuclear Plant at the end of its service life. The companies plan to effect modifications to increase the present spent-fuel storage capacity of the Nuclear Plant to permit normal operations through the early 1990's, at a cost which is not expected to cause a material increase in the construction budget. The companies are also studying alternative methods of decommissioning the Nuclear Plant but cannot reasonably estimate, at this time, the future costs that will be incurred.

The Price-Anderson Act limited the public liability of a licensee of a nuclear plant to \$560,000,000 for a single nuclear incident, to be covered in part by private insurance with the balance to be covered by agreements of indemnity with the Nuclear Regulatory Commission. The Generating Subsidiary has purchased private insurance in the maximum available amount of \$140,000,000. In the event of a nuclear incident involving any commercial nuclear facility in the country, the Generating Subsidiary, together with other licensees, could be individually assessed \$5,000,000 per incident for each reactor owned (subject to a maximum of \$10,000,000 in any year for each reactor owned in the event of more than one incident). The Price-Anderson indemnities have been decreased by the aggregate amount which is assessable against existing licensees and will continue to decrease as new operating units are licensed.

The Generating Subsidiary has procured property insurance in the maximum available amount of \$220,000,000 for damage to the nuclear plant facilities and is a self-insurer for any property loss in excess of that amount.

11. Leases:

The companies, as part of their operations, lease property, plant, and equipment under leases ranging in

length from 2 to 35 years. Most of the leases require the companies to pay related property taxes, maintenance costs, and other costs of operation. The companies expect that in the normal course of business, leases will generally be renewed or replaced by other leases. The greatest part of the rentals is under leases having purchase options or having renewal options for substantially all of the economic lives of the properties.

Rentals are analyzed as follows:

	Year Ended December 31,	
	1978	1977
	(In Thousands)	
Gross Rentals	\$60,000	\$32,000
Less Rental Recoveries (including Sublease Rentals) (a)	<u>1,000</u>	<u>1,000</u>
Net Rentals (b)	<u>\$59,000</u>	<u>\$31,000</u>
(a) Includes amounts paid for or reimbursed by associated companies.		
(b) Classified as:		
Operating Expenses	\$51,000	\$26,000
Clearing and Miscellaneous Accounts (portions of which are charged to income)	<u>8,000</u>	<u>5,000</u>
	<u>\$59,000</u>	<u>\$31,000</u>

Future minimum lease payments, by year and in the aggregate, under the companies' capital leases and noncancelable operating leases consisted of the following at December 31, 1978:

	Capital Leases(a)	Operating Leases
	(In Thousands)	
1979	\$ 6,000	\$ 7,000
1980	6,000	7,000
1981	6,000	7,000
1982	6,000	7,000
1983	5,000	7,000
Later Years	<u>74,000</u>	<u>74,000</u>
Total Future Minimum Lease Payments	103,000	<u>\$109,000</u>
Less Estimated Interest Element Included Therein (b)	<u>61,000</u>	
Estimated Present Value of Future Minimum Lease Payments	<u>\$ 42,000</u>	

(a) Excludes leases of nuclear fuel, all of which are capital leases. Nuclear fuel rentals comprise the unamortized balance of the lessor's cost (approximately \$99,000,000 at December 31, 1978 and \$93,000,000 at December 31, 1977), less salvage value, if any, to be paid over the period of usage in proportion to heat produced, and carrying charges on the lessor's unrecovered cost. It is contemplated that portions of the presently leased material will be replenished by additional leased material.

(b) Interest rates used range from 4.9% to 12.1%.

The following is a pro forma analysis of leased properties under capital leases and related obligations, assuming that such leases were capitalized:

	December 31,	
	1978	1977
	(In Thousands)	
Nuclear Fuel	\$143,000	\$132,000
Coal-Mining and Coal-Transportation Equipment	15,000	17,000
Real Estate	13,000	13,000
Electric Distribution System Property	12,000	12,000
Other	<u>11,000</u>	<u>10,000</u>
Gross Properties under Capital Leases	194,000	184,000
Less Accumulated Provision for Amortization	<u>58,000</u>	<u>53,000</u>
Net Properties under Capital Leases..	<u>\$136,000</u>	<u>\$131,000</u>
Obligations under Capital Leases (a) ..	<u>\$141,000</u>	<u>\$136,000</u>

(a) Including an estimated \$37,000,000 and \$31,000,000, respectively, due within one year.

Had capital leases been capitalized, any additional net expense would have been insignificant. The pro forma data do not give recognition to offsetting adjustments in allowable revenues that the companies believe would normally be expected to occur through the regulatory rate-making process, if the related leases had been capitalized.

Included in the above analyses of future minimum lease payments and of properties under capital leases and related obligations are certain leases as to which portions of the related rentals are paid for or reimbursed by associated companies in the AEP System based on their usage of the leased property. The Company cannot predict the extent to which or proportion in which the associated companies will utilize the properties under such leases in the future.

12. Unaudited Quarterly Financial Information:

The following consolidated quarterly financial information is unaudited but, in the opinion of the Company, includes all adjustments (consisting of only normal recurring accruals) necessary for a fair presentation of the amounts shown:

Quarterly Periods Ended	Operating Revenues	Operating Income	Net Income
	(In Thousands)		
1978—			
Mar. 31.....	\$145,106	\$41,553	\$32,196
June 30.....	157,958	40,183	34,491(a)
Sept. 30.....	152,218	40,749	22,739(b)
Dec. 31.....	148,198	37,349	25,401(a)
1977—			
Mar. 31.....	128,258	31,821	23,191
June 30.....	118,070	30,698	22,871
Sept. 30.....	133,016	33,812	25,817
Dec. 31.....	133,480	34,069	25,241

(a) Includes increases in AFUDC of approximately \$1,567,000 recorded in the second quarter and \$3,372,000 recorded in the fourth quarter relating to changes in AFUDC rates, applied in each case effective as of January 1, 1978.

(b) Includes the effect of a revenue refund (see Note 2), and a change in tax estimate (see Note 3).

13. Unaudited Replacement-Cost Information:

Estimated replacement-cost and related amounts pertaining to depreciation, as of and for the years ended December 31, 1978 and 1977, of productive capacity (as represented by property in service, excluding nondepreciable items such as land and excluding other amounts for which replacement-cost data are not required to be computed) are considerably greater than the related original-cost amounts reported in the consolidated financial statements. A quantitative analysis of such unaudited replacement-cost information is included in the Company's 1978 Annual Report (Form 10-K) to the Securities and Exchange Commission. Reference is made elsewhere herein for information with regard to obtaining a copy of the Company's Form 10-K for the year 1978.

Operating Statistics and Balance Sheet Data

	1978	1977	1976	1975	1974
OPERATING STATISTICS					
ELECTRIC OPERATING REVENUES					
(Thousands):					
From Kilowatt-hour Sales:					
Residential:					
Without Electric Heating	\$ 96,624	\$ 90,833	\$ 71,888	\$ 69,438	\$ 53,265
With Electric Heating	54,067	46,948	37,447	33,493	27,080
Total Residential	150,691	137,781	109,335	102,931	80,345
Commercial	96,370	92,312	72,527	69,176	50,554
Industrial	121,346	109,357	80,233	75,167	63,314
Sales for Resale:					
Municipalities	39,121	44,091	26,841	22,551	23,493
Cooperatives	17,732	15,619	10,491	9,178	7,548
Other Electric Utilities	166,441	103,517	110,382	75,887	55,994
Total Sales for Resale	223,294	163,227	147,714	107,616	87,035
Miscellaneous	7,729	6,062	2,573	4,650	3,389
Total from Kilowatt-hour Sales	599,430	508,739	412,382	359,540	284,637
Other Operating Revenues	4,050	4,085	3,811	3,815	2,969
Total Electric Operating Revenues..	\$603,480	\$512,824	\$416,193	\$363,355	\$287,606
SOURCES AND SALES OF ENERGY (Millions of Kilowatt-hours):					
Sources:					
Net Generated—Steam:					
Fossil Fuel	7,231	7,317	7,701	7,255	8,815
Nuclear Fuel	10,101(a)	4,786	6,809	4,458(a)	—
Net Generated—Hydroelectric	75	68	72	89	73
Net Generated—Other	—	—	—	—	14
Subtotal	17,407	12,171	14,582	11,802	8,902
Purchased	301	182	232	368	694
Net Interchange	4,475	7,922	6,523	6,778	8,451
Total Sources	22,183	20,275	21,337	18,948	18,047
Less: Losses, Company Use, Etc.	1,340	1,270	1,290	1,305	1,335
Net Sources	20,843	19,005	20,047	17,643	16,712
Sales:					
Residential:					
Without Electric Heating	2,352	2,456	2,384	2,374	2,181
With Electric Heating	1,622	1,605	1,577	1,451	1,413
Total Residential	3,974	4,061	3,961	3,825	3,594
Commercial	2,498	2,671	2,579	2,464	2,192
Industrial	4,319	4,473	4,209	3,835	4,134
Sales for Resale:					
Municipalities	1,585	1,642	1,527	1,522	1,847
Cooperatives	814	786	754	690	651
Other Electric Utilities	7,468	5,195	6,849	5,152	4,166
Total Sales for Resale	9,867	7,623	9,130	7,364	6,664
Miscellaneous	185	177	168	155	128
Total Sales	20,843	19,005	20,047	17,643	16,712

(a) Includes 691 million kilowatt-hours in 1978 and 2,309 million kilowatt-hours in 1975 as test generation. The fuel cost associated with such generation is charged to other operation expense.

INDIANA & MICHIGAN ELECTRIC COMPANY
AND GENERATING SUBSIDIARY

AVERAGE COST OF FUEL CONSUMED (a):	1978	1977	1976	1975	1974
Cents per Million Btu:					
Coal	109.68	74.96	65.89	56.09	51.68
Fuel Oil	229.68	168.80	76.72(b)	190.44	187.38
Nuclear	34.65	29.72	26.34	27.83	—
Overall	71.16	59.12	46.47(b)	65.56	69.51
Cents per Kilowatt-hour Generated:					
Coal	1.11	.73	.63	.54	.49
Fuel Oil	2.40	1.88	.84(b)	2.11	1.85
Nuclear38	.33	.28	.30	—
Overall75	.61	.47(b)	.53	.67
RESIDENTIAL SERVICE—AVERAGES:					
Annual Kwh Use per Customer—					
Total	10,260	10,641	10,439	10,305	10,525
With Electric Heating	22,067	22,830	23,200	22,153	23,239
Annual Electric Bill—					
Total	\$ 389	\$ 361	\$ 288	\$ 277	\$ 234
With Electric Heating	\$ 736	\$ 668	\$ 551	\$ 511	\$ 439
Price per Kwh (Cents)—					
Total	3.79	3.39	2.76	2.69	2.22
With Electric Heating	3.34	2.93	2.37	2.31	1.89
NUMBER OF ELECTRIC CUSTOMERS—Year-End:					
Residential:					
Without Electric Heating	315,472	313,085	312,211	310,953	281,904
With Electric Heating	74,900	72,059	69,237	66,812	64,233
Total Residential	390,372	385,144	381,448	377,765	346,137
Commercial	42,106	41,907	41,703	41,456	37,593
Industrial	2,689	2,500	2,452	2,418	2,416
Sales for Resale:					
Municipalities	23	23	23	22	23
Cooperatives	64	61	59	58	58
Other Electric Utilities	20	16	15	18	6
Total Sales for Resale	107	100	97	98	87
Miscellaneous	1,331	1,304	1,280	1,259	1,167
Total Electric Customers	436,605	430,955	426,980	422,996	387,400
BALANCE SHEET DATA—Year-End (Millions)					
Utility Plant	\$ 2,397	\$ 2,107	\$ 1,933	\$ 1,771	\$ 1,630
Accumulated Provision for Depreciation	410	359	317	275	249
Net Utility Plant	1,987	1,748	1,616	1,496	1,381
Total Assets and Other Debits	2,350	2,123	1,914	1,764	1,545
Common Stock, Premium on Capital Stock, and Other Paid-in Capital	527	467	409	367	318
Retained Earnings	137	105	76	80	71
Cumulative Preferred Stock	227	187	147	147	117
Long-term Debt (c)	1,051	1,038	914	895	739

(a) Excludes effect of deferred collection of fuel costs.

(b) Includes effect of refund received from supplier of fuel oil resulting from settlement of litigation concerning pricing. Without such refund, the average cost of fuel oil for 1976 would have been 173.27 cents per million Btu and 1.91 cents per kilowatt-hour generated, and the overall cost of fuel would have been 49.33 cents per million Btu and 0.50 cents per kilowatt-hour generated.

(c) Including Portion Due Within One Year.

Directors

FRANK N. BIEN	GERALD P. MALONEY (a)
W. A. BLACK (f)	RICHARD C. MENGE
LAWRENCE R. BRUNKE	J. F. STARK
RICHARD E. DISBROW	JOHN TILLINGHAST (m)
J. LEE FLANAGAN	W. S. WHITE, JR.
E. W. HERMANSEN	ROBERT O. WHITMAN (b)
G. E. LEMASTERS	

Officers

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J. F. STARK (g) <i>Executive Vice President</i>	PETER J. DEMARIA (d) <i>Treasurer</i>
W. A. BLACK (f) <i>Executive Vice President</i>	H. D. ANDERSON, JR. <i>Assistant Secretary and Assistant Treasurer</i>
J. F. STARK (h) <i>Senior Vice President</i>	ALLEN H. STUHLMANN <i>Assistant Secretary and Assistant Treasurer</i>
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RICHARD E. DISBROW <i>Vice President</i>	CEDRIC L. MAST (j) <i>Assistant Secretary</i>
JOHN E. DOLAN (l) <i>Vice President</i>	WARREN O. KELTNER (k) <i>Assistant Secretary</i>
A. JOSEPH DOWD <i>Vice President</i>	WILLIAM E. OLSON <i>Assistant Secretary</i>
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RICHARD C. MENGE <i>Vice President</i>	WILLIAM N. D'ONOFRIO (i) <i>Assistant Treasurer</i>
JOHN TILLINGHAST (m) <i>Vice President</i>	GERALD R. KNORR (i) <i>Assistant Treasurer</i>
JOHN R. BURTON <i>Secretary</i>	

The principal occupation of each of the above directors and officers of Indiana & Michigan Electric Company, with ten exceptions, is as an officer of American Electric Power Service Corporation of New York, N. Y. The exceptions are the Messrs. W. A. Black, Lawrence R. Brunke, J. Lee Flanagan, E. W. Hermansen, Warren O. Keltner, G. E. LeMasters, J. F. Stark, Richard C. Menge, Allen H. Stuhlmann, and Cedric L. Mast whose principal occupations are as officers of Indiana & Michigan Electric Company, as indicated.

- | | |
|-----------------------------|------------------------------|
| (a) Elected April 25, 1978 | (h) Elected July 1, 1978 |
| (b) Resigned April 25, 1978 | (i) Elected July 1, 1978 |
| (c) Resigned April 27, 1978 | (j) Resigned January 1, 1979 |
| (d) Elected April 27, 1978 | (k) Elected January 1, 1979 |
| (e) Resigned April 27, 1978 | (l) Elected March 1, 1979 |
| (f) Elected July 1, 1978 | (m) Resigned March 29, 1979 |
| (g) Resigned July 1, 1978 | |

Price Range of Cumulative Preferred Stock

By Quarters (1978 and 1977)

Cumulative Preferred Stock	1978—Quarters				1977—Quarters			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th
(\$100 Par Value)								
4½% Series								
Dividends Paid Per Share	\$1.03125	\$1.03125	\$1.03125	\$1.03125	\$1.03125	\$1.03125	\$1.03125	\$1.03125
Market Price—\$ Per Share (OTC)								
Ask (high/low)	—	—	—	—	—	—	—	—
Bid (high/low)	—	—	—	—	40/40	43½/43½	—	—
4.56% Series								
Dividends Paid Per Share	\$1.14	\$1.14	\$1.14	\$1.14	\$1.14	\$1.14	\$1.14	\$1.14
Market Price—\$ Per Share (OTC)								
Ask (high/low)	—	—	—	—	—	—	—	—
Bid (high/low)	—	—	—	—	—	—	46/45	—
4.12% Series								
Dividends Paid Per Share	\$1.03	\$1.03	\$1.03	\$1.03	\$1.03	\$1.03	\$1.03	\$1.03
Market Price—\$ Per Share (OTC)								
Ask (high/low)	46/46	—	—	—	—	—	—	—
Bid (high/low)	45/45	—	—	—	43/43	45/45	45/44	46/44
7.08% Series								
Dividends Paid Per Share	\$1.77	\$1.77	\$1.77	\$1.77	\$1.77	\$1.77	\$1.77	\$1.77
Market Price—\$ Per Share (NYSE)—High	79½	76	77½	77½	81	81¾	83½	80½
—Low	74	69¾	69½	64¼	76½	77½	77	75
7.76% Series								
Dividends Paid Per Share	\$1.94	\$1.94	\$1.94	\$1.94	\$1.94	\$1.94	\$1.94	\$1.94
Market Price—\$ Per Share (NYSE)—High	85	84¼	86¾	82	89	89½	91	89
—Low	80¾	75	76	74	82½	84½	86¾	84
8.68% Series								
Dividends Paid Per Share	\$2.17	\$2.17	\$2.17	\$2.17	\$2.17	\$2.17	\$2.17	\$2.17
Market Price—\$ Per Share (NYSE)—High	98	93	98¾	94½	99	99¾	101½	99¾
—Low	91½	82	83½	82	94½	91	96	94
12% Series								
Dividends Paid Per Share	\$3.00	\$3.00	\$3.00	\$3.00	\$3.00	\$3.00	\$3.00	\$3.00
Market Price—\$ Per Share (NYSE)—High	116	113	113¾	112¾	123	120¾	123¼	121
—Low	111½	109	108¼	103	117	117	118½	113¼
(\$25 Par Value)								
\$2.15 Series*								
Dividends Paid Per Share	\$.5375	\$.5375	\$.5375	\$.5375		\$.215	\$.5375	\$.5375
Market Price—\$ Per Share (NYSE)—High	23¾	22¾	23½	22¾		—	25¾	25
—Low	22¾	20¼	21¼	19¾		—	24½	23¼
\$2.25 Series**								
Dividends Paid Per Share		\$.7125***	\$.5625	\$.5625				
Market Price—\$ Per Share (NYSE)—High		24	24¾	24¾				
—Low		21¾	21¼	20¾				

OTC—Over-the-Counter

NYSE—New York Stock Exchange

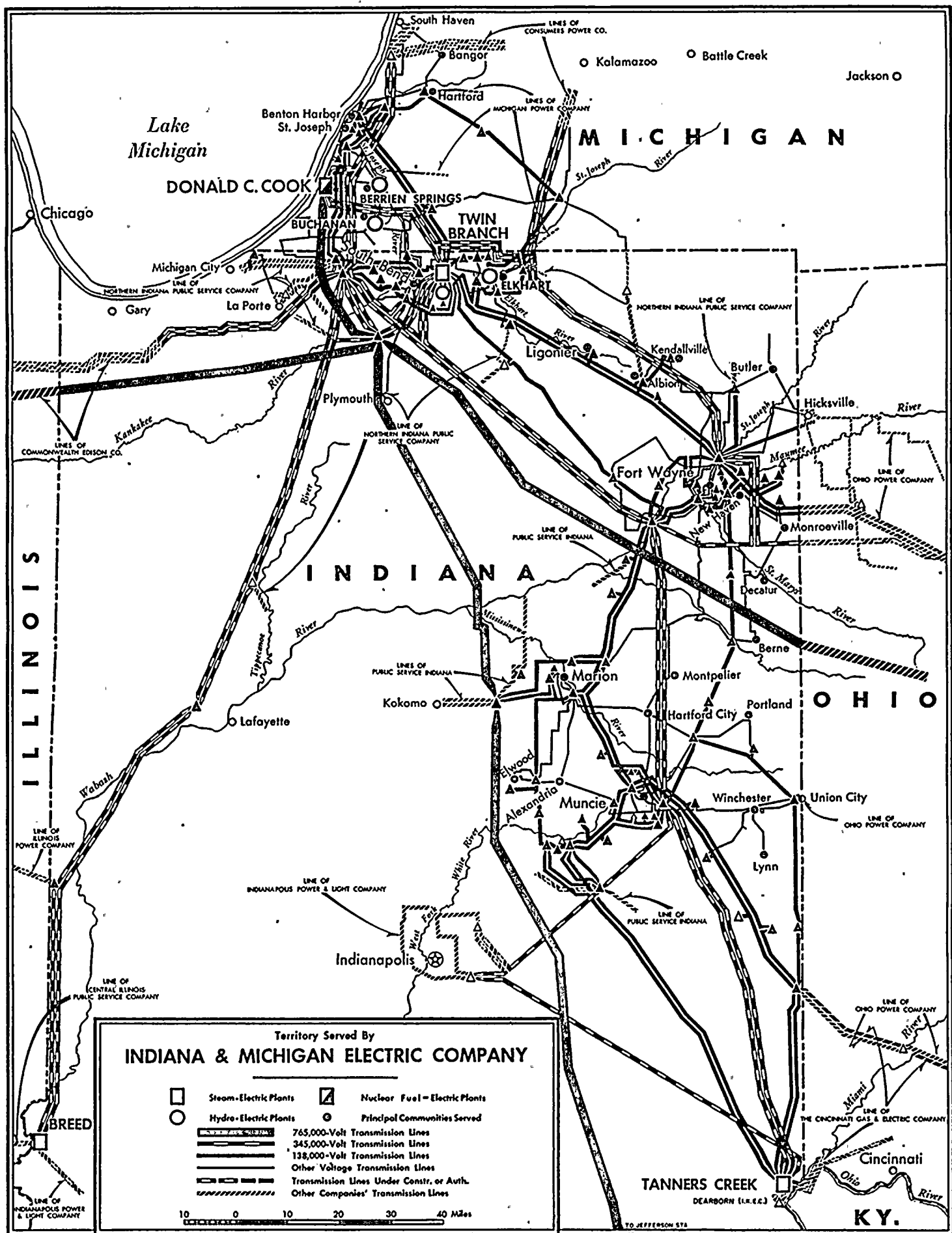
* Issued in May 1977

** Issued in March 1978

*** Includes partial dividend for first quarter.

Note—The above quotations bid and asked represent prices between dealers and do not represent actual transactions.

Market quotations provided by National Quotation Bureau, Inc. — Dash indicates quotation not available.



PREPARED BY AMERICAN ELECTRIC POWER SERVICE CORPORATION • 2 BROADWAY, N. Y. C.

EXXON NUCLEAR COMPANY, INC.

FUEL STORAGE RACKS CORROSION PROGRAM,

BORAL - STAINLESS STEEL

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BORAL - STAINLESS STEEL

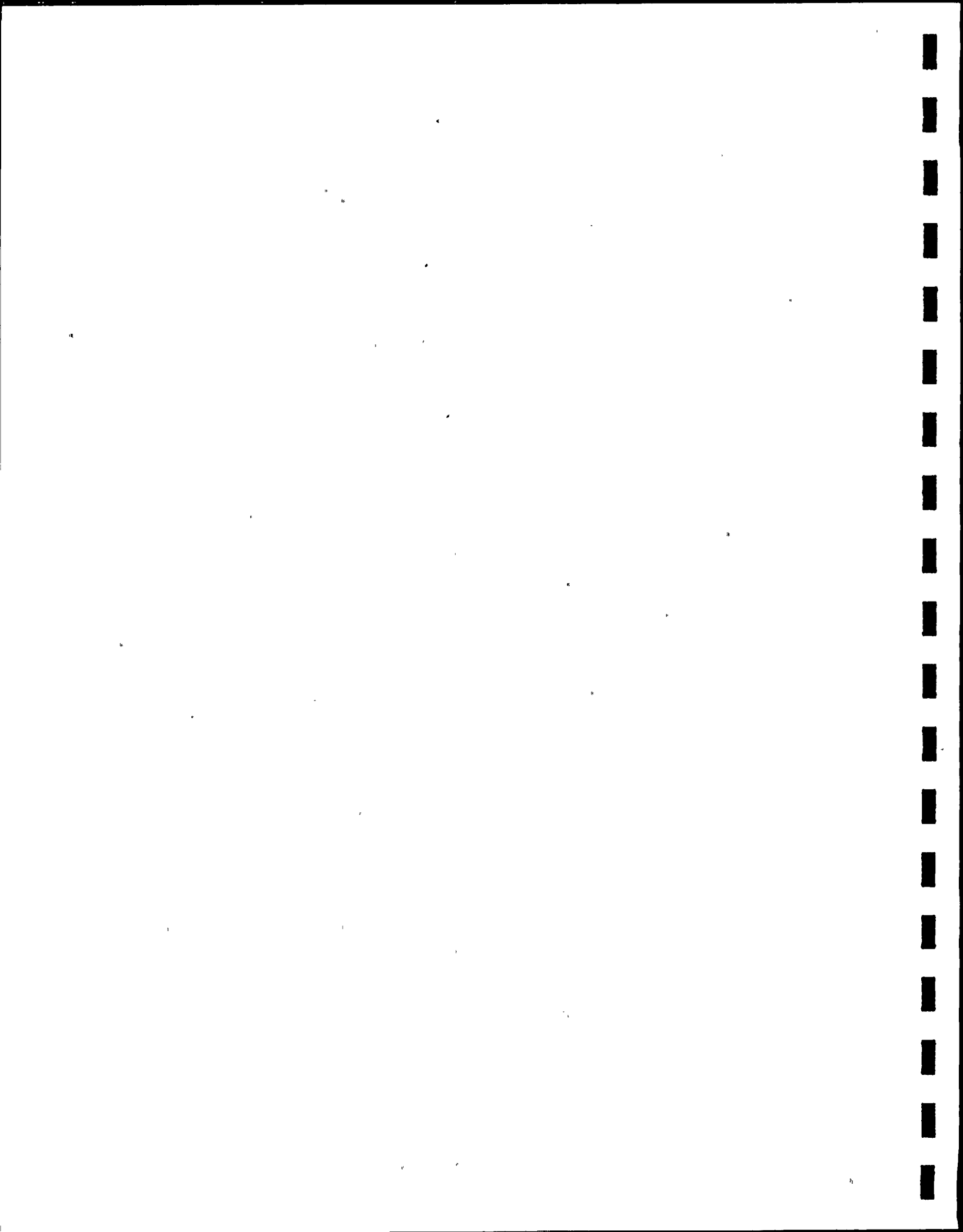
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VALIDATING SIGNATURES

VALIDATING SIGNATURES:

Revision No. and Date

Revised Sections

Revised Pages

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APPENDICES

Appendix A - Test Program (Tables and Figures)

Appendix B - Detailed Test Results (Tables and Figures)

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ABSTRACT

Exxon Nuclear Company, Inc. has conducted a Boral*-Stainless Steel Corrosion Program during the past 18 months to establish additional performance information for use of Boral plates in spent fuel storage applications. The program consisted of a detailed review of related literature, an evaluation of test programs conducted by others, and additional corrosion tests performed at Exxon Nuclear facilities.

The objective of the Exxon Nuclear test program was to obtain corrosion data for Boral-304 stainless steel test specimens in simulated PWR fuel pool environments so that reliable predictions could be made of what physical changes would occur in a defective, i.e., unsealed spent fuel storage cell after a 40-year exposure.

The Exxon Nuclear tests indicate that storage cells, containing a leak simulating hole, will sustain aluminum corrosion at a rate which can be expected to consume 3.25 to 3.4 percent of the aluminum in the Boral core after a 40-year exposure.

Should Boral plates be exposed to a typical PWR pool environment, the material is subjected to pitting, edge attack, and internal gas pressurization; but no effect on criticality safety is expected over the lifetime of storage cells due to dislodgement of B_4C particles.

* The Boral test samples discussed in this report are a neutron absorbing, shielding material manufactured by the Brooks and Perkins Company. The Boral specimens are a composite material consisting of boron carbide evenly dispersed within a matrix of aluminum and clad with aluminum.



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1.0 INTRODUCTION

Prior to designing racks utilizing stainless steel clad Boral plates in PWR pool environments, Exxon Nuclear initiated, (during 1976 and early 1977), a review of applicable material corrosion literature and conducted analyses of test results performed by others.

Exxon Nuclear's review of the related literature*, and performance of Boral in similar environments, indicated that there should be no adverse effect on nuclear safety analyses of storage racks in a PWR pool environment. To provide further assurance of satisfactory material performance, Exxon Nuclear initiated a test program in February, 1977 to evaluate Boral clad in stainless steel 304 specimens in environments simulating utilization in Exxon Nuclear PWR storage rack applications.

* List of appropriate material contained in Reference section of this report.

2.0 TEST PROGRAM DESCRIPTION

2.1 SPECIMEN DESCRIPTION

Exxon Nuclear's test program placed emphasis on investigation of Boral utilized in conditions typical of expected storage cells and PWR pool water environments. Consequently, storage cell component sections were fabricated which resembled the larger, full-size storage cells. Specifically, these reduced-size storage cell specimens consisted of inner and outer stainless steel 304 shrouds into which four (4) Boral plates were inserted. The complete assembly was sealed welded, resulting in 6" high x 6" wide test specimens. Each completed cell specimen was made to simulate a leaking condition by drilling 1/16-inch holes as described in Appendix A.

In order to separately observe and measure various corrosion and material properties during the test, additional test specimens were utilized. These additional specimens consisted of 2" x 2" coupons made as follows:

- 1) Open-edge Boral/stainless steel composite;
- 2) Sealed-edge Boral/stainless steel composites with a leak simulating hole; and,
- 3) Unencapsulated Boral coupons.



2.2

ENVIRONMENT DESCRIPTION

Insulated nine (9) gallon polyethylene tanks, with fitted covers, were used for the plain Boral and open-edged Boral-stainless specimens. Thirty (30) gallon tanks of the same construction were used for the closed-edge tests. Each tank was fitted with a stainless immersion heater and stirring mixer, which were affixed through openings in the tank covers.

A stainless steel screen was used to hold the specimens off the bottom of the tanks and permit circulation of the environment on all sides. In order to isolate the plain Boral specimens from the stainless steel screen, a pedestal was fashioned from phenolic plastic. The open-edged composite samples, a 2" x 2" Boral piece sandwiched between two 2" x 2" stainless steel pieces, were held together with four (4) Met-clip springs, one along each edge. These were placed on the stainless screens so that the clips held the specimens in a horizontal position over the screen.

The initial environment in each tank was deionized water with a pH of 5.85 and a conductivity of 0.75 μ mho/cm. Boric acid (H_3BO_3) and lithium hydroxide ($LiOH \cdot H_2O$) additions were made to produce the following:

Environment A) Deionized water plus 13.3 g/l Boric Acid
(resulting in 2300 ppm Boron at 150°F).

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Environment B) Deionized water, 13.3 g/l Boric Acid,
0.0121 g/l lithium hydroxide

Environment C) Deionized water plus 0.0121 g/l lithium
hydroxide

The specimens, were immersed in each environment on July 1, 1977. The initial temperature and pH of each environment were measured as follows:

<u>Environment</u>	<u>pH</u>	<u>Temperature, °F</u>
1	5.20	146.4
2	5.53	147.2
3	9.15	153.4

The temperature and pH were measured daily. The temperature showed some fluctuations and variacs were installed in order to gain better temperature control. The pH in the borated solutions, 1 and 2, remained constant but in the alkaline tank, C, it dropped into the 7 range within four (4) days. In order to keep the solution pH in the alkaline range; additional additions of lithium hydroxide were made.

2.3

INITIAL MEASUREMENTS

Appendix A of this report contains descriptions of all Boral and stainless steel specimens utilized for the test program. The initial measurements and cleaning programs are also provided in Appendix A.

3.0 SUMMARY.

No corrosion, pitting, nor stress-corrosion cracking was observed on any of the stainless steel coupons, or storage cell specimens used in this study. The austenitic stainless steel can be expected to withstand exposure to borated fuel pool environments for the projected forty-year life of spent fuel racks. Similarly, without a leak path through the stainless steel liners, the interior Boral plates would not be subject to degradation as a result of aqueous corrosion. In the situation of a leak path through the stainless liners which permits the interior space to fill with the pool environments, the results of the 2 month, 6 month, and 12 month exposure studies, show that Boral is subject to general corrosion, pitting and edge attack, and clad deformation due to internal gas pressurization. To various degrees, the severity of each of these corrosion effects depends on the particular environment chemistry and the specific geometry of the exposed materials. Based on comparisons between the four (4) specimen types and the three (3) environments used in this study, the following summary can be drawn concerning the corrosion resistance of Boral and its suitability for use when exposed in stainless lined storage cells to borated environments.

The general corrosion rate, as determined by weight gain measurements, decreased significantly between the 2, 6, and 12 month exposure times. When all the storage cell specimen data are examined on a semi-log plot, the amount of aluminum consumed in conversion to oxide after a 40-year exposure, is: 3.3 percent for the low pH and 3.4 percent for the higher pH environments.



The weight gains were lowest for the storage cell specimens in each of the three (3) environments, followed in general by the plain, open-edged, and edge-sealed specimens. The weight gains, measured for the plain and open-edged specimens, were nearly identical to each other in the three (3) environments. This similarly indicates that galvanic coupling between the stainless steel in the open-edged specimens does not accelerate general corrosion in the Boral. In all three (3) environments, the edge-sealed specimens showed the greatest weight gain.

The high pH environment produces a slightly higher amount of corrosion and, on the average, the highest corrosion rates at the end of the test. This appears to be due to the less protective character of the oxide films formed in the high pH environment.

Pitting was observed on the exterior aluminum surfaces of the Boral after only 18 days of exposure. Pits were observed on the plain specimens in areas beneath the supporting plastic pedestal, which indicates a differential aeration mechanism is operating. Pitting was more extensive in the low pH environment and in those regions of the specimens where ease of replenishment with the bulk solution was greatest. In the storage cell specimens, pitting was confined only to those areas near the leak simulating holes; also these specimens showed the least number of pits.

The frequency of pitting did not increase significantly with increased exposure time. The size and depth of the pits continued to increase, however. The maximum pit depth, after 12 months, was 0.032". As pitting progresses into the Boral some aluminum binder is corroded and the B_4C particles become embedded in corrosion products.

Similar considerations apply to edge attack of the Boral. However, the depth of edge attack did not increase significantly between the

6 and 12 month exposure. The deepest edge penetration, 0.028", was measured on the open-edged specimen in the low pH environment. No measurable edge attack was observed in the vicinity of the leak simulating hole in the Boral plates of the storage cell specimens.

Gas generation, due to corrosion of the aluminum in Boral, has been observed in the edge-sealed specimens and the storage cell specimens. This gas has been observed to bubble from the upper hole in each of the storage cells. In several of the specimens removed after 12 months, bulges were observed between the aluminum cladding and the B_4C aluminum core. (See Figures 4.2 and 4.3, Appendix B). Internal gas generation, blocked from escape by the buildup of corrosion products in conjunction with occasional un-bonded layers of the Boral matrix, is believed to be the cause of these bulges.

The occasional unbonded layers of the Boral matrix occurred randomly and were observed in concentrated areas of very small B_4C particles (i.e., ≥ 150 mesh). It has been determined that the Boral specimens provided by Brooks and Perkins for the ENC corrosion test program contained a much higher concentration of small B_4C particles than utilized for production Boral plates. Accordingly, it is possible that the small bulges observed on the sealed specimens may not occur in finished plates where improved B_4C and aluminum bonding result with larger B_4C particles.

The occasional lack of bonding between B_4C and aluminum particles also allows a small amount of water to enter the inner portions of the bulged specimens. Normally, water does not penetrate into well-bonded Boral plates and no internal corrosion can occur.

The small bulges have not been reported or observed in prior related corrosion test programs. They appear to be a self-limiting phenomenon,



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where the gaseous corrosion product both causes the bulge and displaces the water causing the corrosion. An inspection of both the aluminum cladding and inner Boral matrix demonstrates that no clad pitting or deterioration of the inner face of cladding and Boral material occurred near the bulged areas. Consequently should random small bulges occur, any dislodgement of B_4C particles will be of no significance on neutron shielding or attenuation properties.



4.0 RESULTS

On June 30, 1978, after a nominal 12-month exposure, the remaining three (3) plain Boral and three open-edged Boral-stainless composite specimens, were removed from the three (3) heated tanks. On August 10, 1978, the edge-sealed, and storage cell specimens, were removed from their environments. These twelve (12) samples were subjected to visual, metallographic, weight gain, and pit depth measurement analyses.

This section of the report places emphasis on the detailed results obtained from the storage cell specimens. Appendix B presents additional test results for other specimens and contains most referenced tables and figures for information presented in this section. Table 4.1 provides specimen identification numbers and exact lengths of exposure for each of the twelve (12) specimens evaluated during the final period.

4.1 Internal Environment Of Edge-Sealed And Storage Cell Specimens

The pH of the solution, within the edge-sealed and storage cell specimens, was measured using indicator paper for the former, and a Beckmann pH meter for the latter. Approximately 2.5 grams of solution was contained in the edge-sealed specimens and 39 grams in the cell specimens.

In Table 4.2 is a summary of the interior pH of the edge-sealed and cell specimens for the 2-, 6-, and 12-month exposures.



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For the high pH lithium environment, the interior pH consistently shows a decrease in pH toward a neutral value for all exposure times. A similar trend toward a more neutral pH is exhibited for the acidic environments for exposures up to 6-months. After 12-months, the interior pH is the same as the bulk solution or, slightly more acidic.

4.2 Visual Appearance

The storage cell specimens were disassembled and cut open to separate the Boral plates from the stainless liners. A visual examination of each Boral piece was conducted using a low power stereo-microscope. The following observations were noted:

Storage Cell Specimen #3 (S.C.S.-3)

Surfaces were generally metallic in coloration. Extra corrosion products, and some pitting, were seen on the faces and along the edges where the leak simulating holes were drilled through the stainless liners.

Storage Cell Specimen #6 (S.C.S.-6)

Specimens are darker than SCS-3. Pitting is much less. Rust existed along edges where holes were drilled. Bulges were observed in the dimple area of plate S.C.S.-6(1), on both the outside and inside.

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Specimens were white in coloration with rust colored deposits along the edges where holes were drilled. B_4C stringers were evident, but no pitting. Plate S.C.S.-9(4) had a 1-1/4" pure aluminum strip on one short edge.

4.3. Weight Gain

After the visual analysis, the appropriate Boral plate specimens were weighed, oven-dried, and reweighed in order to determine the amount of absorbed moisture in the core and the change in weight due to exterior and interior corrosion. The specimens were dried in stages in an air-circulating oven for two (2) hours at 150, 200, 250°F, and for 24 hours at 300°F. The original weight, the weight prior to oven-drying, and the dried weight for each specimen, is listed in Table 4.3.

A summary of the moisture absorbed weight percentages, for the 2-month, 6-month, and 12-month exposures, is given in Table 4.4. The overall average for all specimens, environments, and exposures, was 0.47%. This corresponds to a minimum average porosity level in the Boral core of approximately 1.5%. The absorbed moisture decreased between 2-months and 6-months and increased between 6-months and one year. This may be the result of an initial decrease in porosity as corrosion products were generated in the core followed by a porosity increase as additional corrosion enlarged the pores. The greatest moisture absorption occurred in the open-edged specimens in the A environment. This specimen also showed the greatest number of pits and would, therefore, contain the greatest amount of material capable

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of absorbing moisture. The least moisture, on the average, was in the storage cell Boral plates, which may be due to their larger size and lower edge to volume ratio.

In Table 4.5, the corrosion weight gain percentages are summarized for all the specimens tested in the program. The values, in brackets, have been corrected to account for the fact that certain of the 6" x 4" Boral plates in the cell specimens contain a strip of solid aluminum along one edge. Since this strip did not contain the normal porous core structure, it could contribute weight gain only by external surface corrosion. To make valid comparisons, using these specimens, their weight was reduced by a factor corresponding to the reduced core volume. Under the assumption that the weight gain percentages are an indication of the extent of uniform corrosion in these specimens, the results presented in Table 4.5 show that the corrosion rates have decreased with increased exposure time. The results are plotted for each specimen type as a function of environment in Figures 4.4 through 4.6.

The weight gains are largest for the edge-sealed specimens in each environment. Similarly, they are the smallest for the storage cell specimens. In between, with very similar results, are the plain and open-edged specimens. The similar weight gains, experienced by these two (2) specimen types, show that the general corrosion is not accelerated due to coupling with stainless steel.

When the weight gain values for the storage cell specimens are considered on a semi-logarithmic scale, the relationship appears to be amenable to extrapolation, as shown in Figures 4.7 through 4.9. From these figures, the extrapolated weight gain percentage and the calculated percent of aluminum consumed after 40 years exposure, are:

<u>Environment</u>	<u>Weight Gain, %</u>	<u>Al Consumed, %</u>
A	4.4	3.3
B	4.5	3.4
C	4.5	3.4

4.4 Pitting

To evaluate the extent of pitting in the 12-month exposure specimens, the corrosion products were cleaned from the surfaces of a portion of one of the four (4) plates from each cell specimen. A summary of the pitting frequency and pit depth, for the 6-month and 12-month exposures, is given in Table 4.6. The pit diameter for the 12-month specimens is also given in the table.

Table 4.6 shows that the pitting characteristics after 12-months were very similar to those after 6-months. Those specimens and environment combinations which did not pit or showed little pitting tendency after 6-months, showed no or few pits after 12-months, however, those with significant pits after 6-months had a large number of pits after 12-months. Increased pitting was observed in the plain specimens in the A environment and in the edge-sealed specimens in the A and B environments. The other specimens showed nearly the same number of pits after 12-months as after 6-months.

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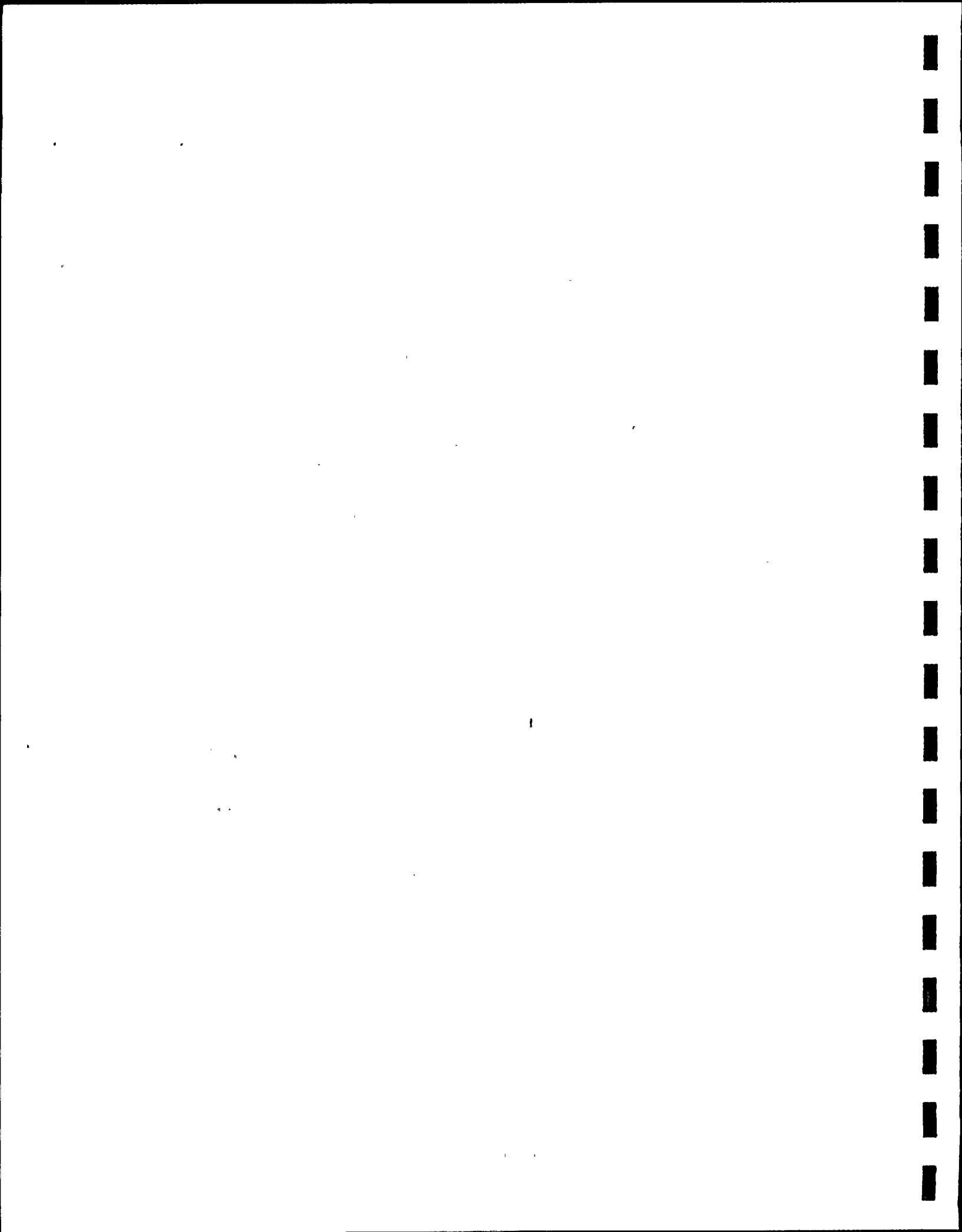
The pit depth, however, increased with the extended 12-month exposure. In some cases where pits had not penetrated the aluminum clad in 6-months, they had done so after 12 months.

4.5 Metallography

Sections of Boral from each specimen were mounted and metallographically polished in order to observe the thickness of surface oxidation films, the depth of edge attack, the undercutting around drilled holes, and the nature of surface bulges. Sections were made along an edge for the plain and open-edged specimens, and through the drilled hole in the Boral for the edge-sealed and storage cell specimens. In addition, sections through bulges in the specimens were made to characterize these structures. The specimens were back-filled with epoxy under vacuum conditions to impregnate surface porosity, then rough polished on silicon carbide papers and final polished on diamond using automatic vibratory equipment.

4.5.1 Surface Corrosion Films

The surface corrosion films on several of the specimens were thick enough to measure using a filar eye piece at a magnification of 400. The film thickness, as measured for these specimens, is listed in Table 4.7. The thickness for the C environment specimens was thickest, being a maximum of 8.2 microns for the plain specimen. Where the bulge in this specimen caused the surface layer to break apart, the corrosion films were much thicker. Appendix B contains photographs showing the surface film in one area away from a bulge and, for comparison, on a bulge.



4.5.2 Edge Attack

Table 4.7 also shows the depth of corrosive attack at the Boral coupon edges in the plain and open-edged specimens. The attack was greatest in the A environment and was somewhat greater in the open-edged specimen than in the plain specimen. Only one specimen of the six (6) edge-sealed and storage cell types showed accelerated corrosion around the partially drilled leak simulating hole. This was the edge-sealed specimen in the C environment. The similarity in edge attack between the plain and open-edged specimens again indicates a lack of corrosion acceleration due to galvanic coupling of the Boral to stainless steel.

4.5.3 Bulges

Several bulges were observed on the 12-month exposure specimens. Similar bulges were not observed on specimens exposed for 2- or 6-months. Table 4.8 lists the number of bulges observed on each specimen. Photographs demonstrating bulged areas are shown on Figures 4.2 and 4.3.

The bulges are separations between the aluminum clad and the B₄C-aluminum matrix. They appear to result from gas pressure caused by internal corrosion. The corrosion of aluminum would generate hydrogen gas following the reaction



Such gas generation has been observed in the edge-sealed and storage cell specimens. To generate a bulge would require sealing of the edges with corrosion products to enable the internal gas pressure to increase sufficiently to expand the ten mil aluminum cladding. The edge-sealed specimens each had four (4) bulges. These specimens also showed the largest corrosion weight gains which could result in the sealing of edges in these specimens.

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APPENDIX ABORAL SPECIMENS

Thirty (30) pieces of Boral, 2" x 2", were received from Brooks and Perkins. Twenty-seven (27) were used in the tests and the remaining held for spares and basic metallography. The Boral material is 0.078-inches thick with an aluminum clad thickness of 0.010-inches, and a B_4C -aluminum matrix thickness of 0.058-inches. The core contains a minimum of 0.020 grams, per square centimeters, of B^{10} .

The samples to be used in the tests were numbered according to a Controlled Test Procedure. The Boral pieces were cleaned ultrasonically for 5 minutes in reagent grade alcohol, rinsed in alcohol, and air-dried. The two (2) surfaces of each piece were then photographed at a magnification of 1.5X to record the initial microscopic condition.

In order to determine the initial weight of each Boral sample, they were dried in an oven at 300°F for one hour, cooled in a desiccator, and weighed. The weight of each piece is listed in Table 2.1. Specimens 19-27 were weighed after a 1/16" hole had been drilled in the center of one face to an approximate depth of .040-inches.

STAINLESS STEEL SPECIMENS

The stainless steel samples (T-304 2B Stainless Sheet) were cleaned and passivated according to the following schedule: Ultrasonically cleaned in detergent water for 30 minutes and tap water rinsed, passivated in room temperature 15% nitric acid for 30 minutes, rinsed in distilled water, and wiped dry.

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The specimens were then oven-dried at 300°F for one hour, cooled in a desiccator, and weighed. The sample number, size, and weights are given in Table 2.2. Specimens 19a-27a were weighed after a 1/16" hole was drilled through the center of each.

EDGE-SEALED AND STORAGE CELL SPECIMENS

The nine (9) edge-sealed specimens were made of a 2" x 2" Boral coupon sandwiched between two (2) 2-1/2" x 2-1/2" stainless pieces. The perimeter of the sandwich was sealed with RTV sealant in such a way that a gap, approximately 1/4" deep, exists between the sealant and the Boral edge. A 1/16" hole was drilled through one of the stainless liners and into the Boral, approximately .040-inch deep, at the center of one face. The coupons were filled with the appropriate solution and ingress to the interior occurs through the center hole. The depth of the hole, in each Boral coupon, is listed in Table 2.3.

The storage cell samples were received from Brooks and Perkins on July 7, 1977. Each of the nine (9) cell samples were weighted with the following results:

<u>Storage Cell Specimen</u>	<u>Weight Kg</u>
1	2.754
2	2.700
3	2.694
4	2.705
5	2.716
6	2.719
7	2.725
8	2.727
9	2.753



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Three (3) 1/16" holes were drilled through the stainless steel shroud to enable the environment to enter the interior of the shroud to simulate a leak. Two (2) holes were drilled through the steel liner adjacent to the longitudinal welds on opposite sides of the cell specimen. The holes were located at the space just above the Boral plates at the top and bottom of the steel liner. A third hole was drilled in the center of the face with the exterior longitudinal weld which penetrated through the stainless liner and partially into the Boral plate.

TABLE 2.1

<u>Specimen No.</u>	<u>Weight, gms.</u>
1	13.07534
2	12.92862
3	13.15619
4	13.01482
5	12.50052
6	12.94034
7	12.65638
8	12.45607
9	12.67761
10	12.78939
11	12.73945
12	13.04195
13	12.83988
14	12.97783
15	13.16179
16	12.25492
17	12.70607
18	12.88145
19	12.73691
20	12.76902
21	12.81245
22	12.74536
23	12.82162
24	12.79287
25	12.31567
26	13.00877
27	12.74711

TABLE 2.2

<u>No.</u>	<u>Size</u>	<u>Weight, gms.</u>	<u>No.</u>	<u>Size</u>	<u>Weight, gms.</u>
10a	2"x2"	38.89595	19a	2-1/2"x2-1/2"	60.79322
10b	"	39.82520	19b	"	61.05405.
11a	"	38.89082	20a	"	60.84419
11b	"	39.68805	20b	"	60.94462
12a	"	38.53197	21a	"	61.03033
12b	"	38.68259	21b	"	61.39631
13a	"	39.56829	22a	"	61.41475
13b	"	38.40278	22b	"	60.85141
14a	"	40.03330	23a	"	60.90979
14b	"	39.96712	23b	"	61.79174
15a	"	38.85374	24a	"	61.00493
15b	"	38.63247	24b	"	61.08312
16a	"	38.82814	25a	"	60.93235
16b	"	38.75806	25b	"	60.80852
17a	"	38.63605	26a	"	60.88068
17b	"	38.41275	26b	"	60.78854
18a	"	39.01611	27a	"	60.75921
18b	"	38.70722	27b	"	60.78874

TABLE 2.3

<u>Specimen No.</u>	<u>Hole Depth (Inches)</u>
19	.047
20	.035
21	.035
22	.035
23	.039
24	.047
25	.047
26	.051
27	.047

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APPENDIX B

- Section 4.0 (Tables and Figures)
- Supplemental Test Results For Other Test Specimens

TABLE 4.1SPECIMEN IDENTIFICATION NUMBER AND EXPOSURE TIME*

<u>Environment</u>	<u>Plain Boral</u>	<u>Open-Edged</u>	<u>Exposure (Days)</u>
A (Boron)	2	12	364
B (Boron and Lithium)	4	15	364
C (Lithium)	8	17	364

<u>Environment</u>	<u>Edge-Sealed</u>	<u>Storage Cell Specimen**</u>	<u>Exposure (Days)</u>
A (Boron)	21	S.C.S.-3 (1,2,3,4)	370
B (Boron and Lithium)	24	S.C.S.-6 (1,2,3,4)	370
C (Lithium)	27	S.C.S.-9 (1,2,3,4)	364

* A total of 36 specimens were utilized during the test program. Specimens not listed above were evaluated during the 2-month and 6-month evaluation phases.

** Values in parenthesis are the four (4) individual Boral plates contained within the storage cell specimens.

TABLE 4.2

INTERIOR SOLUTION pH

<u>Environment</u>	<u>Exposure</u>	<u>Bulk pH</u>	<u>Edge-Sealed</u>	<u>Storage Cell</u>
A (Boron)	2 Mo.	5.0	-	5.8
	6 Mo.	5.0	6.1	5.9
	12 Mo.	4.8	5.0	5.0
B (Boron and Lithium)	2 Mo.	5.6	-	6.0
	6 Mo.	5.7	6.5	5.9
	12 Mo.	5.6	5.0	5.2
C (Lithium)	2 Mo.	8.5	-	7.9
	6 Mo.	9.2	7.5	7.8
	12 Mo.	9.6	7.0	7.8

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NUCLEARTABLE 4.312-MONTH EXPOSURE WEIGHT OF BORAL PLATESFROM STORAGE CELL

<u>Cell/ Plate</u>	<u>Original Wt. (gms)</u>	<u>Weight As Removed (gms)</u>	<u>Weight As Dried (gms)</u>	<u>Δ W On Drying (gms)</u>	<u>Δ W Corr. (gms)</u>
<u>S.C.S.-3</u>					
(1)	76.8973	79.26654	78.82035	-0.44619	+1.92305
(4)	77.6335	78.83673	79.47447	-0.36226	+1.84097
(3)	78.3163	80.57643	80.13166	-0.44477	+1.81536
(2)	76.7407	78.95639	78.61309	-0.34330	+1.87239
<u>S.C.S.-6</u>					
(2)	76.5611	78.84505	78.54603	-0.29902	+1.98493
(3)	77.2583	79.35079	79.12012	-0.23067	+1.86182
(4)	76.7592	78.17358	78.01435	-0.15923	+1.25515
(1)	77.7683	80.42402	80.09471	-0.32931	+2.32641
<u>S.C.S.-9</u>					
(3)	78.0971	80.74073	80.44607	-0.29466	+2.34897
(4)	78.0672	80.12927	79.96575	-0.16352	+1.89855
(1)	77.1018	79.47767	79.22429	-0.25338	+2.12249
(2)	77.0113	79.08118	78.89541	-0.18577	+1.88411

TABLE 4.4
MOISTURE ABSORPTION WEIGHT PERCENTAGE SUMMARY

Specimen Type	Weight Loss Percentage On Drying								
	A Environment			B Environment			C Environment		
	<u>2 Mo.</u>	<u>6 Mo.</u>	<u>12 Mo.</u>	<u>2 Mo.</u>	<u>6 Mo.</u>	<u>12 Mo.</u>	<u>2 Mo.</u>	<u>6 Mo.</u>	<u>12 Mo.</u>
Plain	0.44	0.39	0.71	0.40	0.30	0.41	0.42	0.17	0.55
Open-Edged	0.62	0.59	1.27	0.55	0.31	0.57	0.70	0.22	0.55
Sealed-Edged	0.53	0.37	0.65	0.63	0.36	0.55	0.49	0.28	0.59
Storage Cell Specimen (4 Plate Average)	<u>0.29</u>	<u>0.41</u>	<u>0.54</u>	<u>0.33</u>	<u>0.32</u>	<u>0.33</u>	<u>0.23</u>	<u>0.48</u>	<u>0.29</u>
4 Specimen Average	0.47	0.44	0.79	0.48	0.32	0.46	0.46	0.29	0.50

TABLE 4.5
CORROSION WEIGHT GAIN PERCENTAGE (%)

<u>Specimen Type</u>	<u>A Environment</u>			<u>B Environment</u>			<u>C Environment</u>		
	<u>2 Mo.</u>	<u>6 Mo.</u>	<u>12 Mo.</u>	<u>2 Mo.</u>	<u>6 Mo.</u>	<u>12 Mo.</u>	<u>2 Mo.</u>	<u>6 Mo.</u>	<u>12 Mo.</u>
Plain	1.68	2.85	3.34	1.79	2.83	3.06	1.84	2.99	3.63
Open-Edged	2.00	2.91	2.85	1.94	2.93	3.03	2.21	3.24	3.81
Sealed-Edged	2.18	3.62	3.81	2.19	3.12	3.96	2.69	4.10	4.46
Storage Cell Specimen (4 Plate Average)	<u>1.39</u>	<u>1.94</u>	<u>2.41</u>	<u>(1.49)</u>	<u>(2.00)</u>	<u>(2.54)</u>	<u>(1.73)</u>	<u>(1.98)</u>	<u>2.66</u>
4 Specimen Average	1.81	2.83	3.10	1.83	2.72	3.12	2.12	3.08	3.64

B-6

TABLE 4.6
SUMMARY OF PIT MEASUREMENTS
AFTER 6-MONTH AND 12-MONTH EXPOSURE

<u>Specimens and</u> <u>(Environment)</u>	<u>Exposure</u>	<u>Total Pit/Area</u> <u>(#/sq. in.)</u>	<u>Thru Clad</u> <u>Pit/Area</u> <u>(#/sq.in.)</u>	<u>Max. Pit</u> <u>Depth</u> <u>(in.)</u>	<u>Pit</u> <u>Diameter</u> <u>(in.)</u>
<u>Plain</u>					
2(A)	12 Mo.	3.7	2.3	0.032	0.16
1(A)	6 Mo.	1.2	0.5	0.015	--
4(B)	12 Mo.	--	--	--	--
5(B)	6 Mo.	--	--	--	--
8(C)	12 Mo.	--	--	--	--
9(C)	6 Mo.	--	--	--	--
<u>Open-Edged</u>					
12(A)	12 Mo.	13.3	10.0	0.020	0.19
10(A)	6 Mo.	11.8	5.1	0.019	--
15(B)	12 Mo.	2.5	1.5	0.021	0.07
13(B)	6 Mo.	2.9	0.6	0.013	--
17(C)	12 Mo.	3.8	2.2	0.018	0.13
16(C)	6 Mo.	3.0	0.3	0.011	--
<u>Sealed-Edged</u>					
21(A)	12 Mo.	3.9	0.7	0.015	0.06
20(A)	6 Mo.	1.1	--	--	--
24(B)	12 Mo.	5.2	0.9	0.019	0.04
23(B)	6 Mo.	0.3	--	--	--
27(C)	12 Mo.	--	--	--	--
26(C)	6 Mo.	0.2	0.2	0.017	--
<u>Storage Cell Specimens</u>					
S.C.S.-3(A)	12 Mo.	0.7	0.1	0.014	0.07
S.C.S.-2(A)	6 Mo.	0.9	0.2	0.011	--
S.C.S.-6(B)	12 Mo.	0.1	--	--	--
S.C.S.-5(B)	6 Mo.	0.3	0.1	0.012	--
S.C.S.-9(C)	12 Mo.	--	--	--	--
S.C.S.-8(C)	6 Mo.	--	--	--	--



TABLE 4.7
SURFACE OXIDE THICKNESS AND DEPTH OF UNDERCUTTING

<u>Specimen and (Environment)</u>	<u>Undercutting At Edge and Hole (in.)</u>	<u>Oxide Thickness (Microns)</u>
2(A)	0.020	3.5
12(A)	0.028	Not Measurable
21(A)	Not Measurable	2.9
S.C.S-3(A)	Not Measurable	Not Measurable
4(B)	0.008	3.6
15(B)	0.007	4.6
24(B)	Not Measurable	Not Measurable
S.C.S-6(B)	Not Measurable	Not Measurable
8(C)	0.005	8.2
17(C)	0.009	Not Measurable
27(C)	0.014	5.5
S.C.S.-9(C)	Not Measurable	Not Measurable

TABLE 4.8

BULGES OBSERVED ON 12-MONTH EXPOSURE SPECIMENS

<u>Specimen</u>	<u>Type</u>	<u>Height (in.)</u>	<u>Diameter (in.)</u>	<u>Environment</u>
3 (1)	S.C.S.	.004	.23	A
3 (2)	S.C.S.	--	--	A
3 (3)	S.C.S.	--	--	A
3 (4)	S.C.S.	--	--	A
6 (1)	S.C.S.	.003	.3	B
6 (1)	S.C.S.	.009	.25	B
6 (1)	S.C.S.	.005	.2	B
6 (1)	S.C.S.	.017	.25	B
6 (1)	S.C.S.	.005	.3	B
6 (2)	S.C.S.	--	--	B
6 (3)	S.C.S.	--	--	B
6 (4)	S.C.S.	--	--	B
9 (1)	S.C.S.	--	--	C
9 (2)	S.C.S.	--	--	C
9 (3)	S.C.S.	--	--	C
9 (4)	S.C.S.	--	--	C
2	Plain	--	--	A
12	Open-Edge	.009	.4	A
21	Edge-Seal	.027	.54	A
21	Edge-Seal	.008	.49	A
21	Edge-Seal	.020	.43	A
21	Edge-Seal	.015	.40	A
4	Plain	--	--	B
15	Open-Edge	--	--	B
24	Edge-Seal	.009	.26	B
24	Edge-Seal	.01	.29	B
24	Edge-Seal	.004	.2	B
24	Edge-Seal	.003	.25	B
8	Plain	.086	1.43	C
8	Plain	.004	.15	C
17	Open-Edge	--	--	C
27	Edge-Seal	.014	.47	C
27	Edge-Seal	.026	.51	C
27	Edge-Seal	.027	.9	C
27	Edge-Seal	.010	.39	C

B-9

FIGURE 4.1 (Photograph 1)

PRETEST BORAL SPECIMEN

(With Large Number of Unbonded Areas)

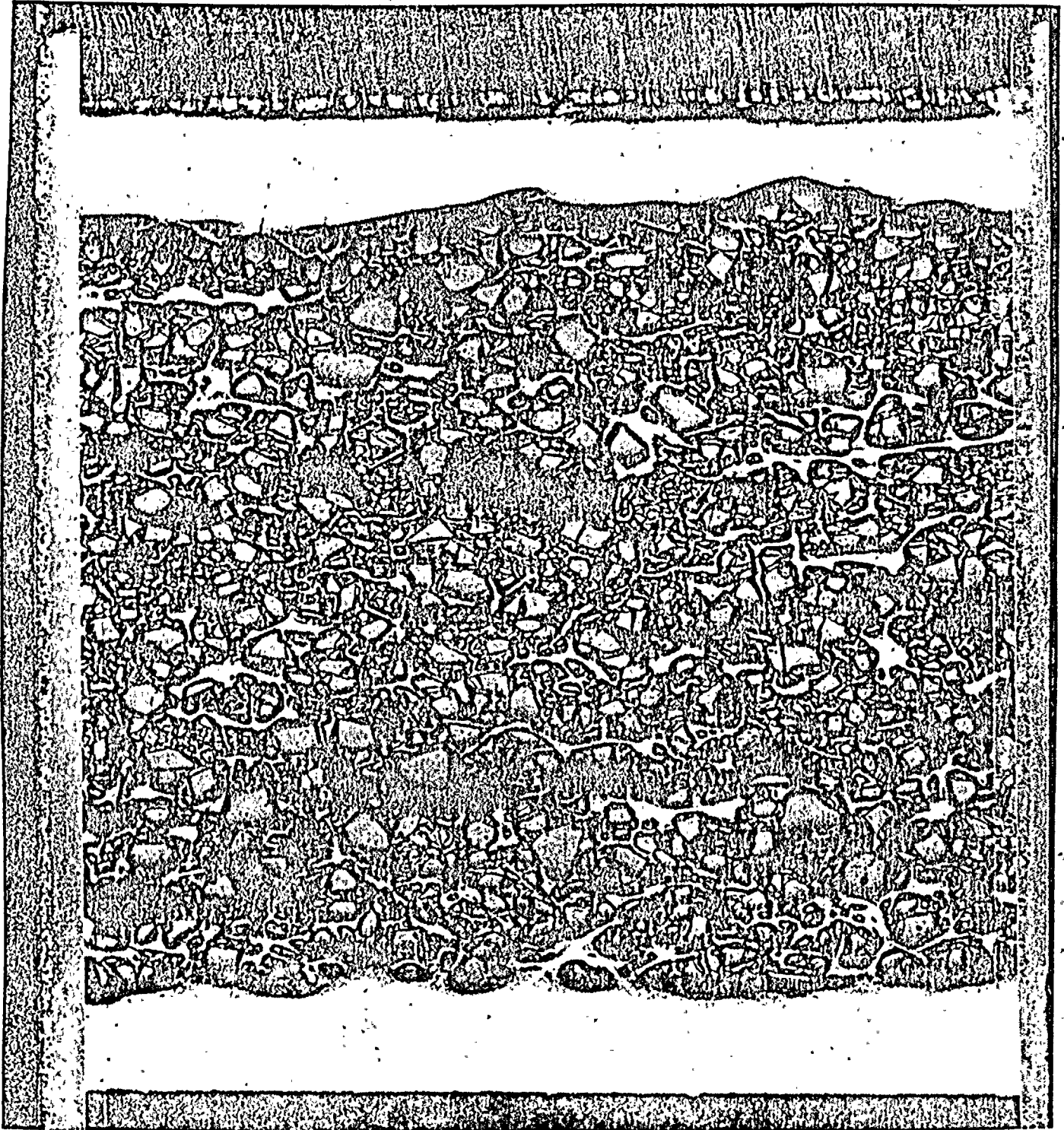


FIGURE 4.1 (Photograph 2)

PRETEST BORAL SPECIMEN

(With Few Areas of Unbonded Layers)

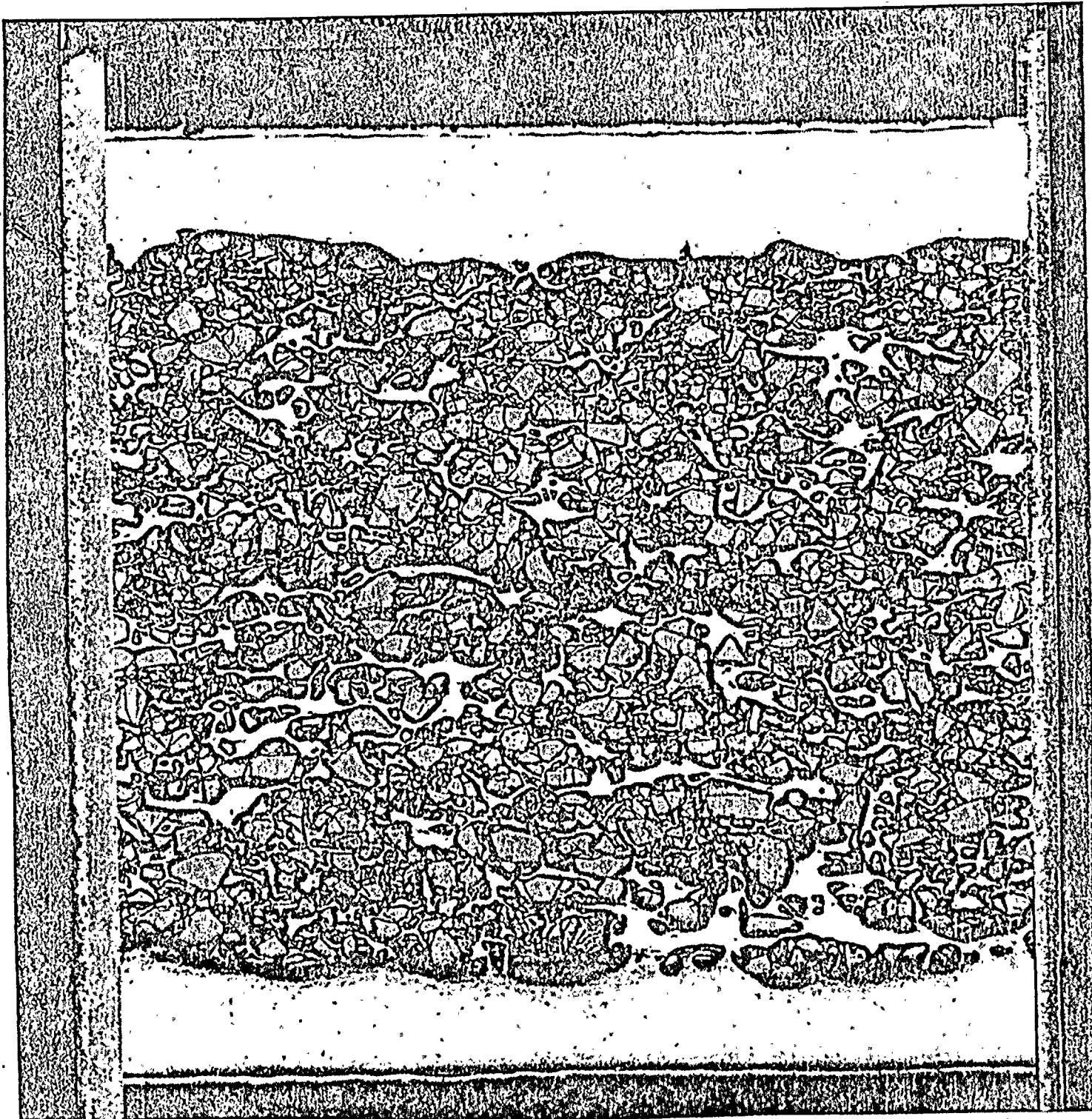
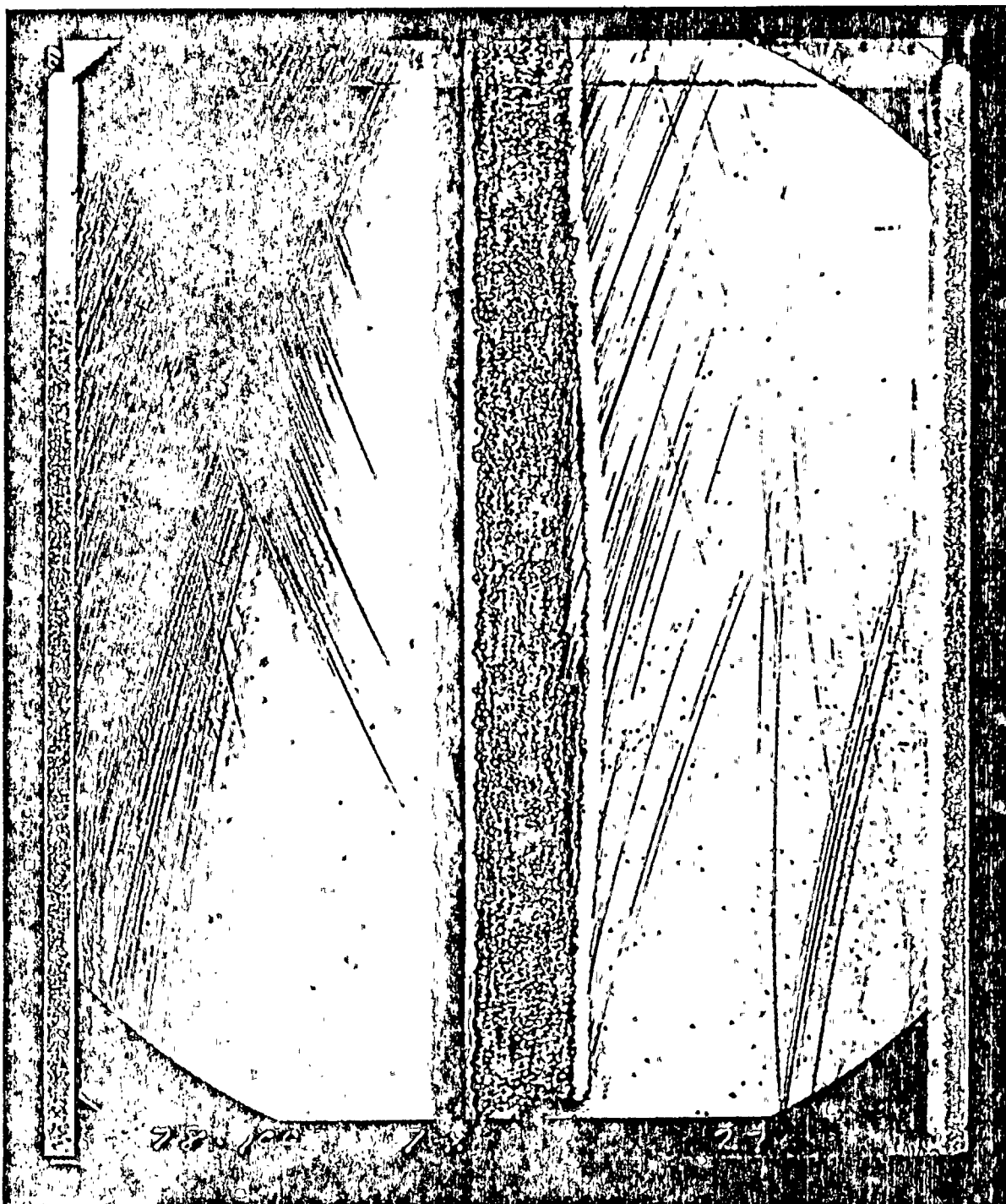


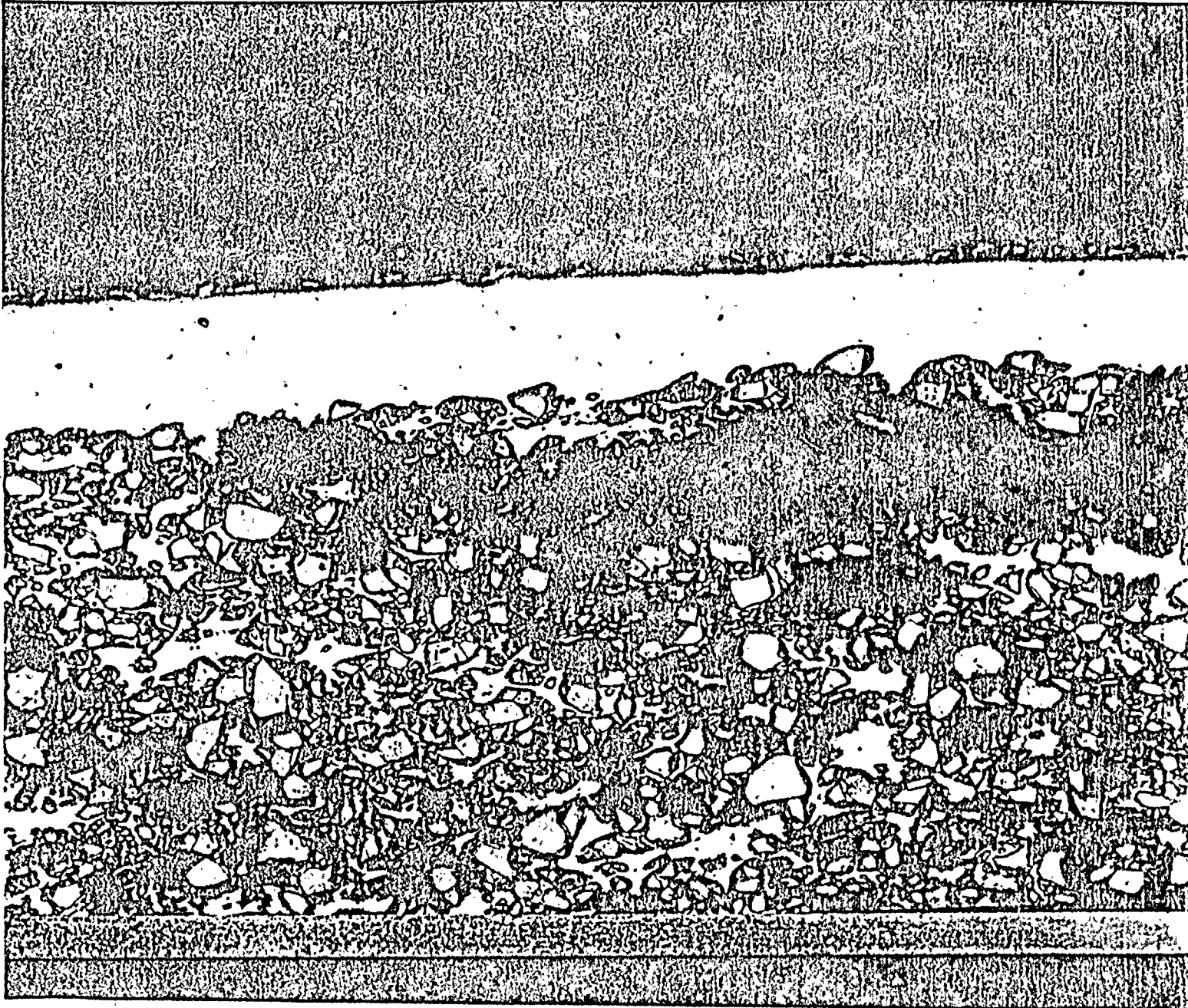
FIGURE 4.2
SIDE VIEW OF BULGED BORAL SPECIMEN



NOVEMBER 1978

FIGURE 4.3

CLOSEUP VIEW OF BULGED SPECIMEN*



* Note the lack of inner surface corrosion or pitting on the aluminum cladding.

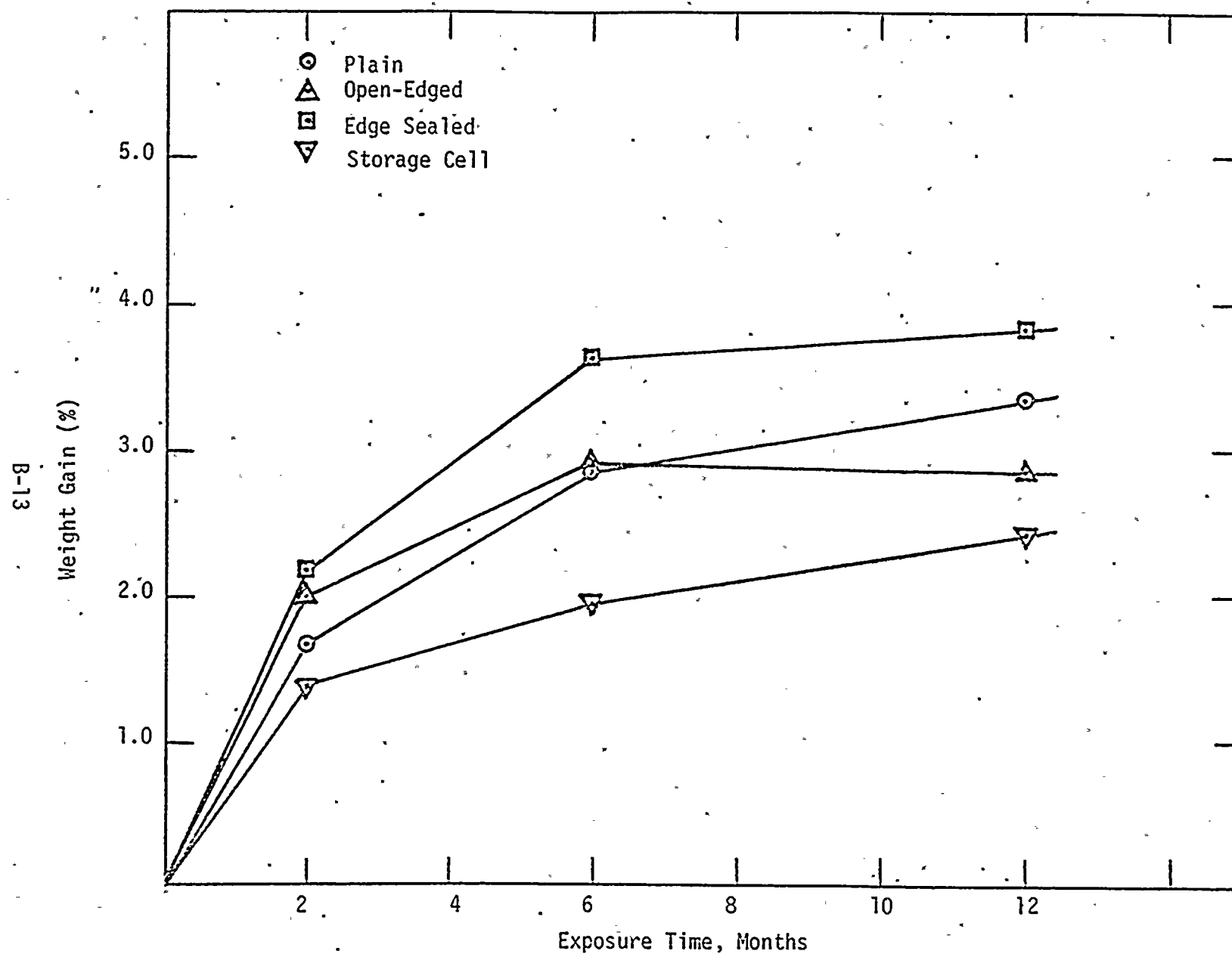


FIGURE 4.4 Weight Gain Percentage for "A" Environment Specimens.

B-14

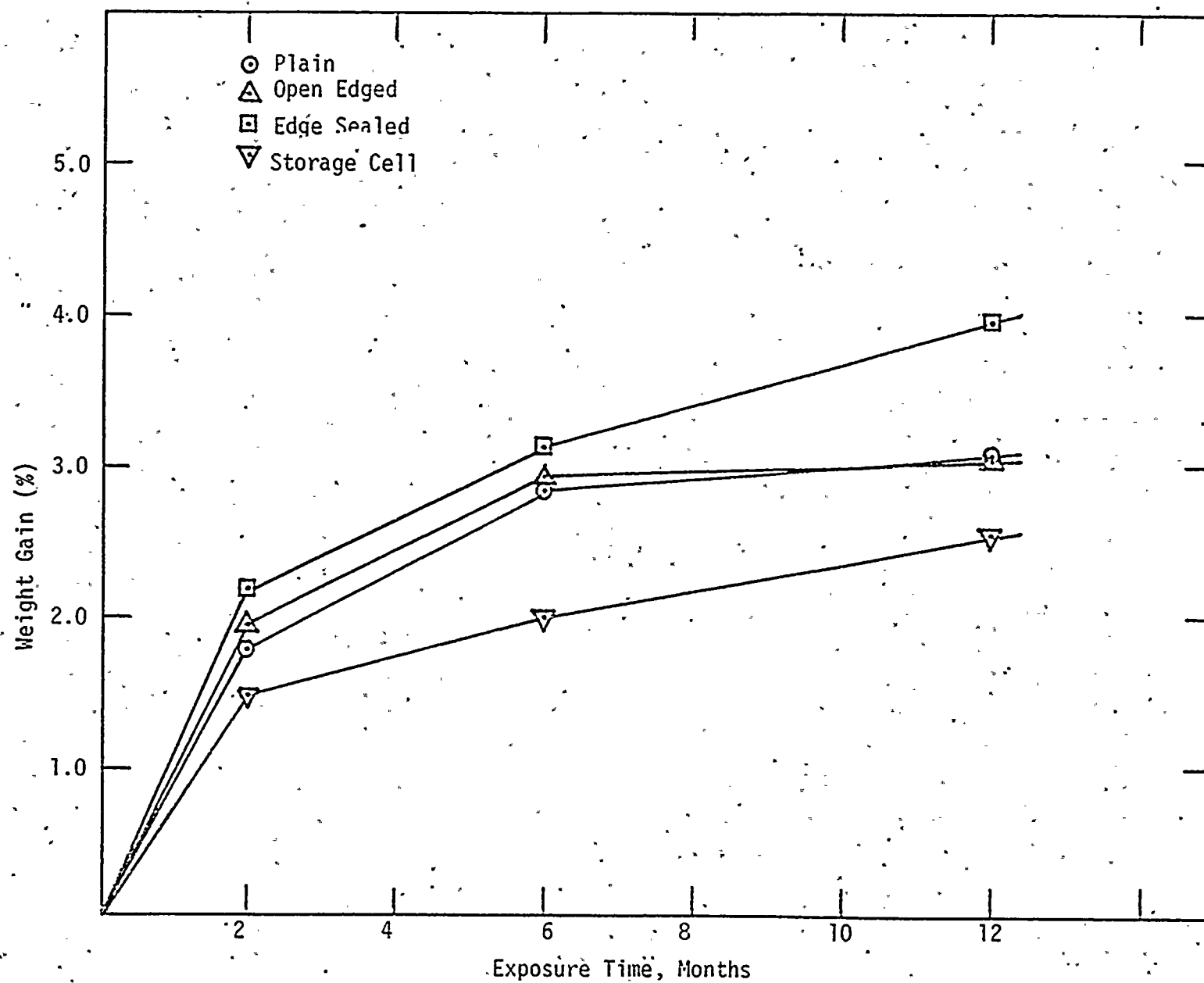


FIGURE 4.5 Weight Gain Percentage Versus Time For "B" Environment Specimens

B-15

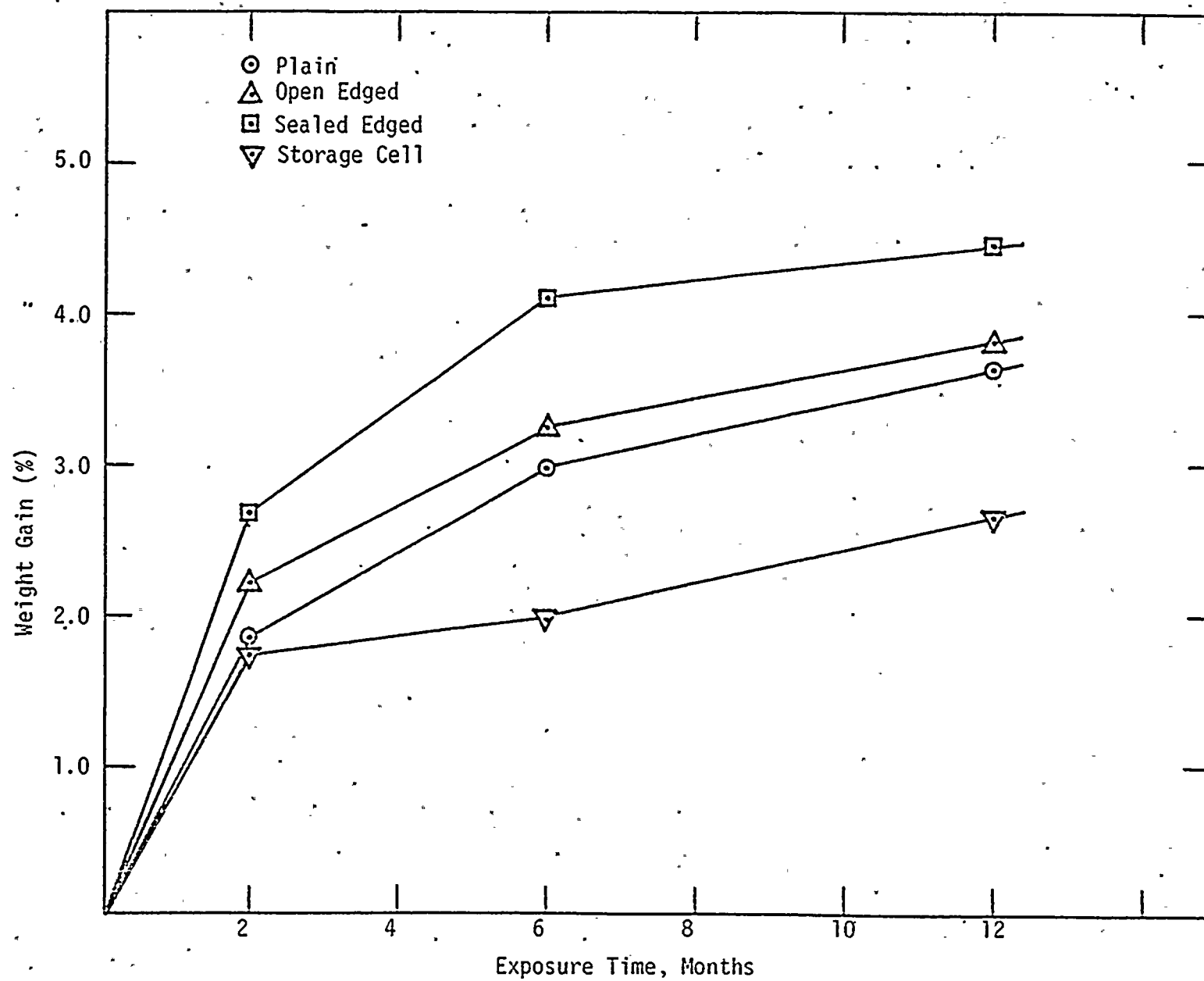


FIGURE 4.6 Weight Gain Percentages Versus Time For "C" Environment Specimens.



B-16

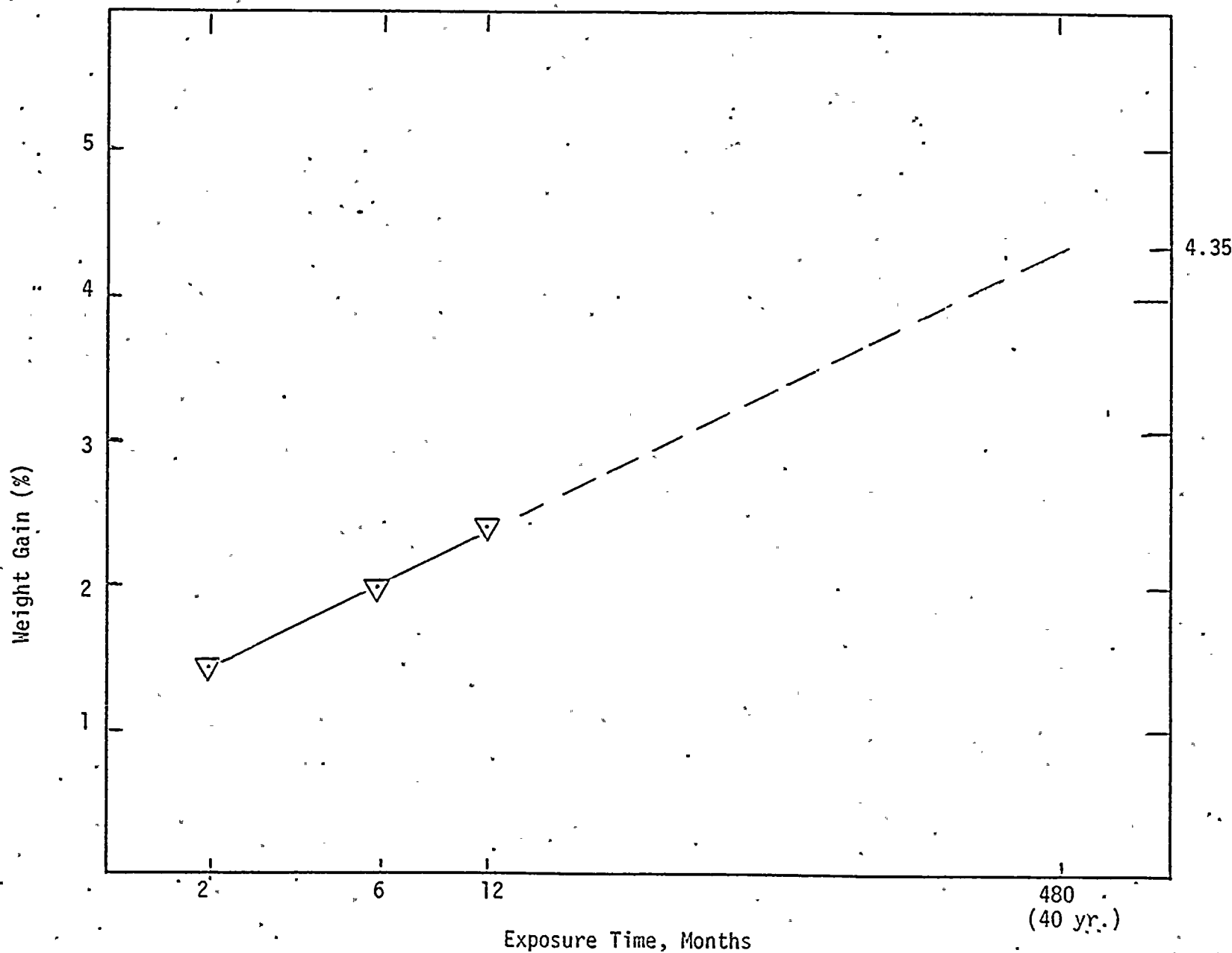


FIGURE 4.7 Semi-Log Plot Showing Weight Gain Percentage For "A" Environment Storage Cell Specimens, Extrapolated to 40 Years.

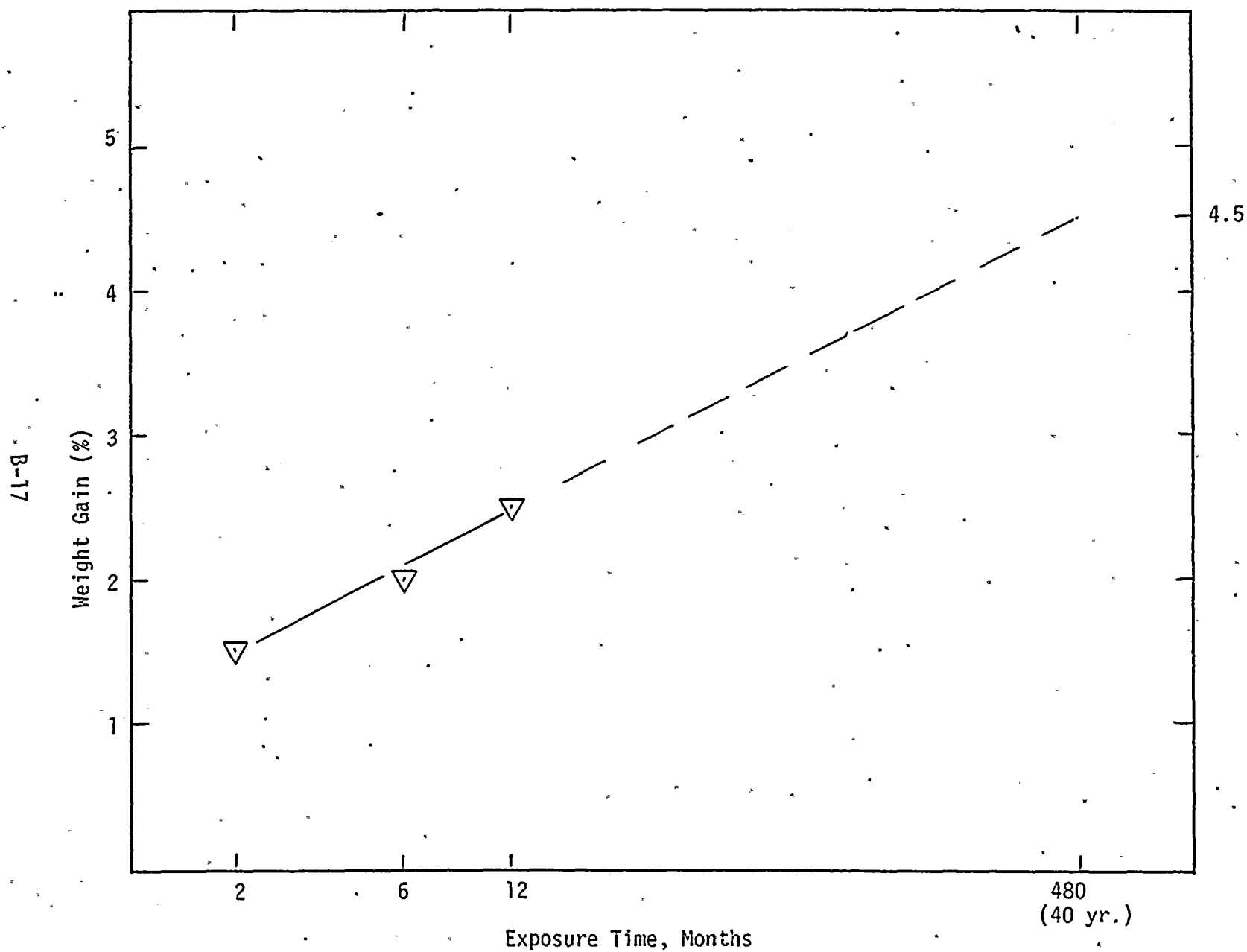


FIGURE 4.8 Semi-Log Plot Showing Weight Gain Percentage for "B" Environment Storage Cell Specimens, Extrapolated to 40 years.

B-18

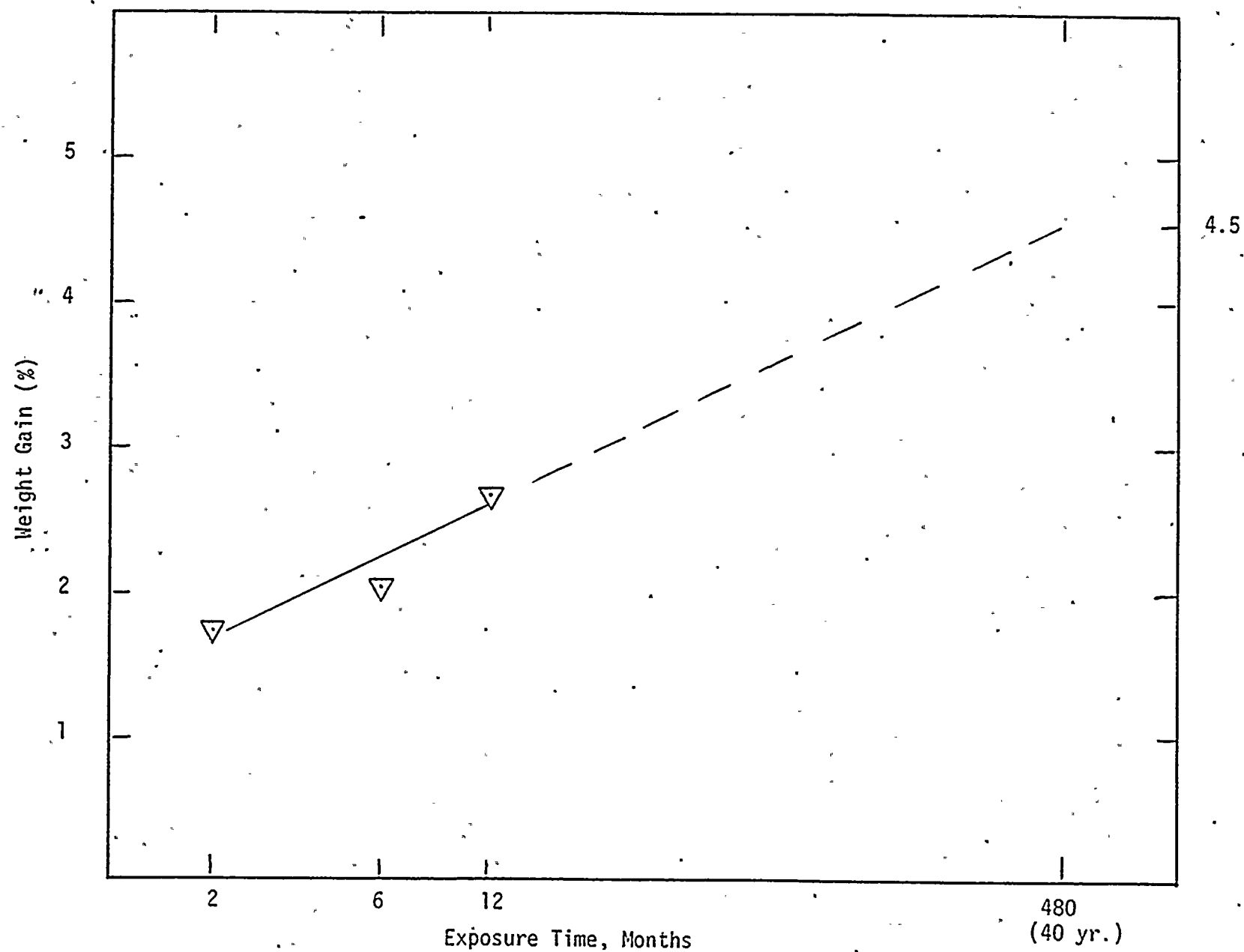


FIGURE 4.9 Semi-Log Plot Showing Weight Gain Percentage for "C" Environment Storage Cell Specimens, Extrapolated to 40 years.

12-MONTH EXPOSURE WEIGHT OF NON-STORAGE CELL BORAL SPECIMENS

<u>Specimen & Environment</u>	<u>Original Wt.(gms)</u>	<u>Weight As Removed (gms)</u>	<u>Weight As Dried (gms)</u>	<u>Δ W On Drying (gms)</u>	<u>Δ W Corr. (gms)</u>
2 (A)	12.92862	13.45214	13.36061	-0.09153	+0.43199
4 (B)	13.01482	13.46598	13.41246	-0.05352	+0.39764
8 (C)	12.45607	12.97673	12.90873	-0.06800	+0.45266
12 (A)	13.04195	13.57893	13.41358	-0.16535	+0.37163
15 (B)	13.16179	13.63607	13.56057	-0.07550	+0.39878
17 (C)	12.70607	13.26022	13.19047	-0.06975	+0.48440
21 (A)	12.81245	13.38430	13.30083	-0.08347	+0.48839
24 (B)	12.79287	13.36994	13.30008	-0.06986	+0.50721
27 (C)	12.74711	13.39136	13.31581	-0.07555	+0.56870

SUPPLEMENTAL VISUAL INSPECTION OBSERVATIONS

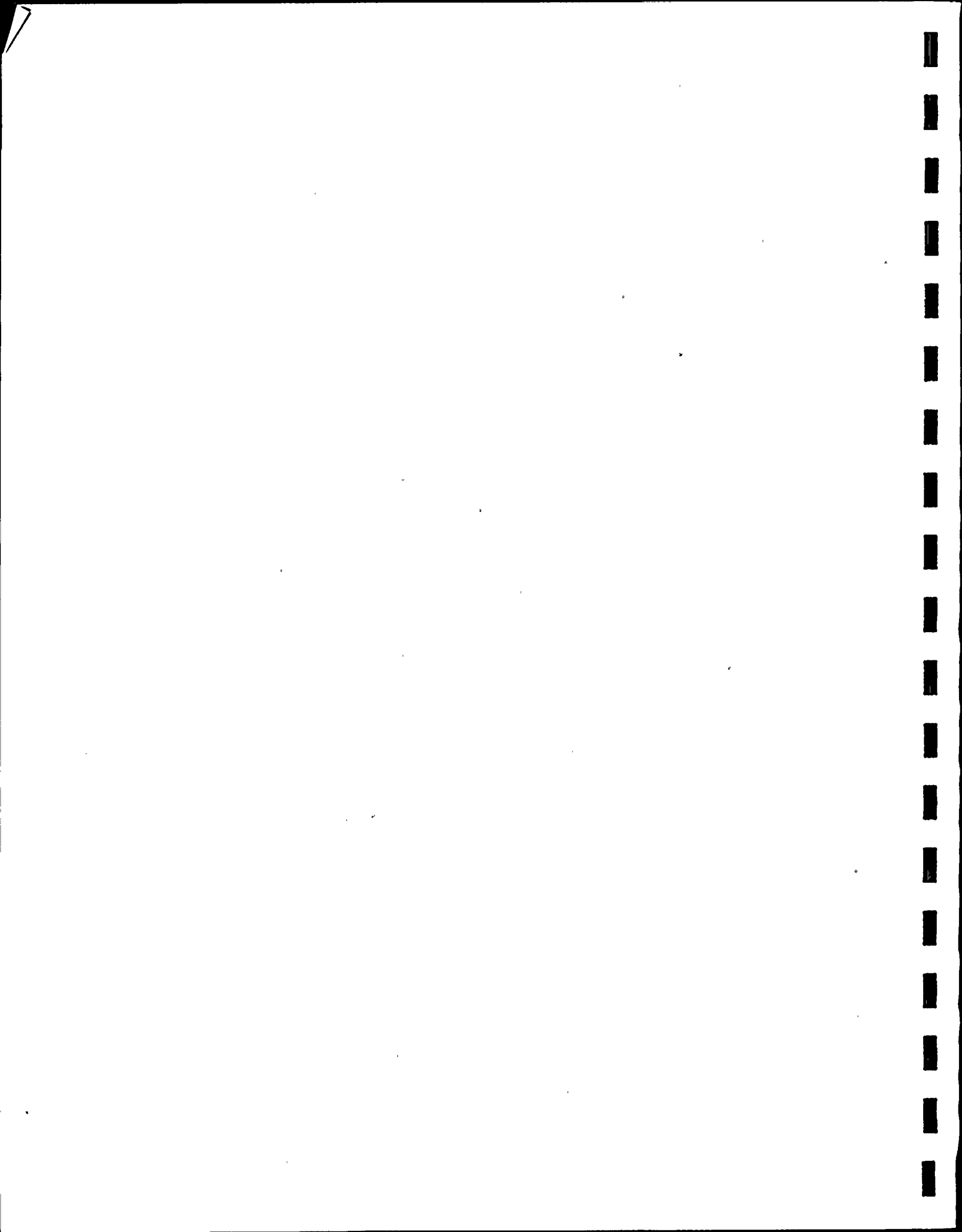
Specimen #2 - Very uniform light tan surface coating. Several pits were evident under the pedestal area and the edges were completely covered with white tan corrosion products.

Specimen #4 - Uniform and tightly adherent dark grey surface coating. No pits under pedestal area and the edges were black but showed no corrosion products except a few rust streaks.

Specimen #8 - Very light grey or straw surface coloration. Three (3) black spots, one about 1-inch in diameter, corresponded to areas where the surface clad had bulged away from the B_4C aluminum matrix. The black spots were made up of stripes and looked as if the deformation associated with the bulge had broken the protective oxide film, allowing rapid corrosion of the underlying metal. Similar bulges were seen on six (6) of the other specimens and are discussed in another section of this report.

Specimen #12 - Both sides showed pitting along the edges. The surface coloration was grey with white and brown corrosion products as in the plain specimen from the A environment.

Specimen #15 - The surface coloration was darker than the A tank specimen but showed less pitting.



Specimen #17 - The surface coloration was light grey and the exposed edges were covered with loosely adherent white corrosion products. Some pits near edges.

Figure 2 shows the edge-sealed specimens from the three (3) environments. The surfaces are those where the leak simulating hole was drilled through the stainless cover and partially through the Boral. The coloration is similar to what was observed in the plain and open-edged specimens. The amount of corrosion products on the specimen edges, however, was much less.

Specimen #21 - White and rust colored corrosion products around the center hole and some white corrosion on edges. Shallow pitting was on some areas but no pits evident through the cladding. A small bulge existed on side opposite hole.

Specimen #24 - Rust stain around the hole and some B_4C stringers showing but few, if any, deep pits.

Specimen #27 - Coloration is white on light grey. Two (2) bulges, one large on hole side and one small opposite. Edges are heavily covered with white corrosive products.

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CALVERT CLIFFS UNIT I
CYCLE 4

June, 1980

REPORT OF POWER DISTRIBUTION EPISODE

October 1979 - May 1980

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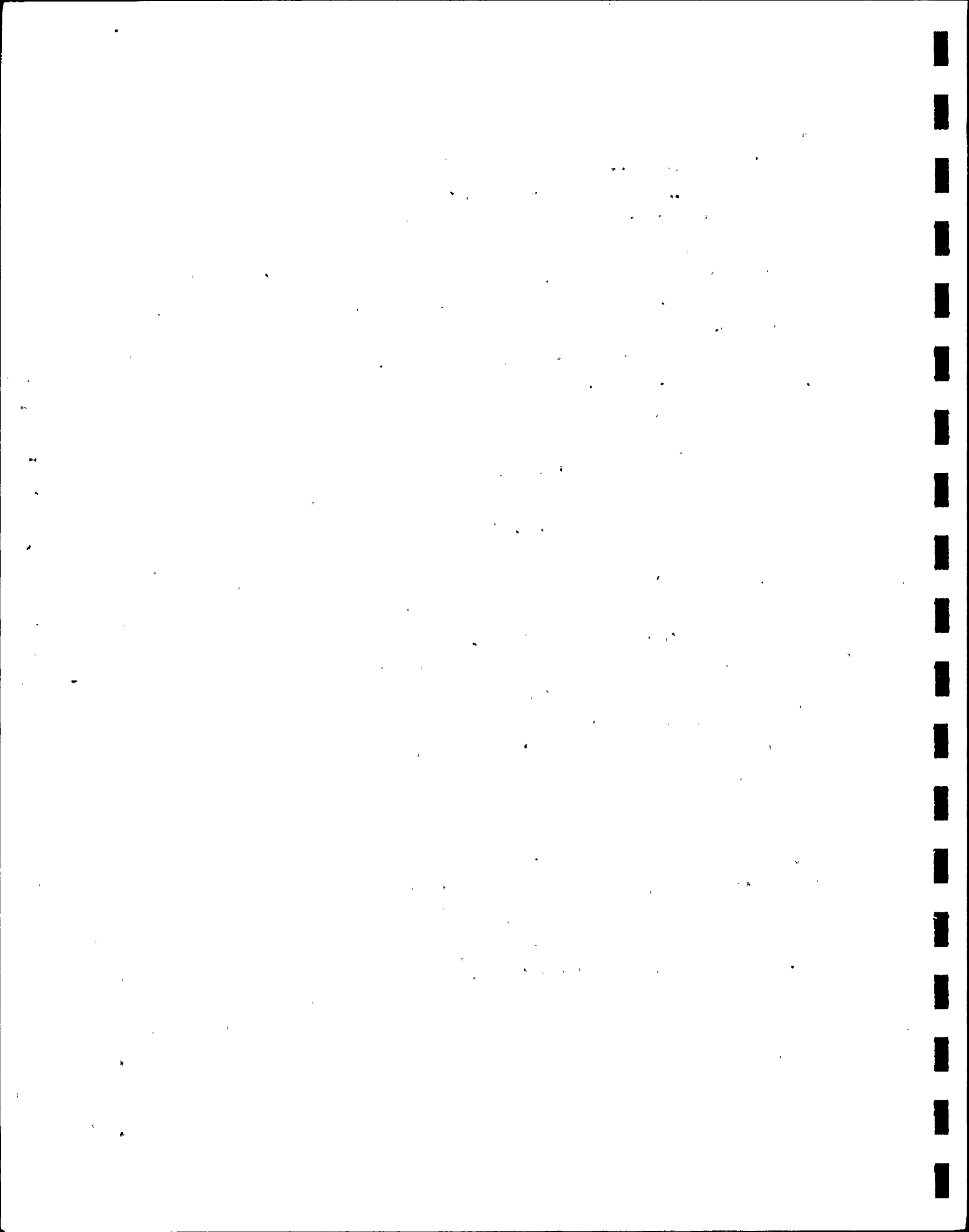
I. SUMMARY

In late October, 1979, Calvert Cliffs Unit 1 Reactor Core began to exhibit unpredicted behavior. The local power distribution began to grow asymmetric axially and an abnormal shift in power to the core periphery began to occur. The initiation of the core power distribution change proceeded by about two weeks the beginning of a slow increase in differential pressure across the reactor core. The increase in differential pressure across the reactor core peaked at 1.8 psid, 13% above normal. The supposition was that the increase in differential pressure reflected deposition of crud on core surfaces. The crud acted as a neutron absorber and/or insulator, thereby, forcing a core power redistribution.

Concern for the effect of the anomalous core behavior on the safety analysis and the crud layer on fuel integrity led to successive power level decreases until 50% was reached in early November.

The crud was postulated to consist of corrosion products from Reactor Coolant System (RCS) surfaces. The higher than normal amount of corrosion products were probably caused by an abnormally high ingress of Oxygen into the RCS. The source of that ingress was found and isolated in late October. By this time, the axial power imbalance had reached a peak of 11%. The combination of power level decreases and isolation of the Oxygen source coincided with a slowing and eventual reversal of the growth in axial power imbalance. However, core differential pressure (dp) remained at 1 to 1.8 psid above normal.

Plant Site and Combustion Engineering Task Forces were organized to determine the cause of anomalous core behavior, to assess its effect on plant safety, and to seek a resolution. A comprehensive diagnostic program was implemented including development of a model of the phenomenon. The Task Forces labored from early November through late January, 1980. Meanwhile, the situation slowly corrected itself and by late January, all core parameters, with the exception of core dp, were near normal. Core dp was still 1.8 psid above normal.

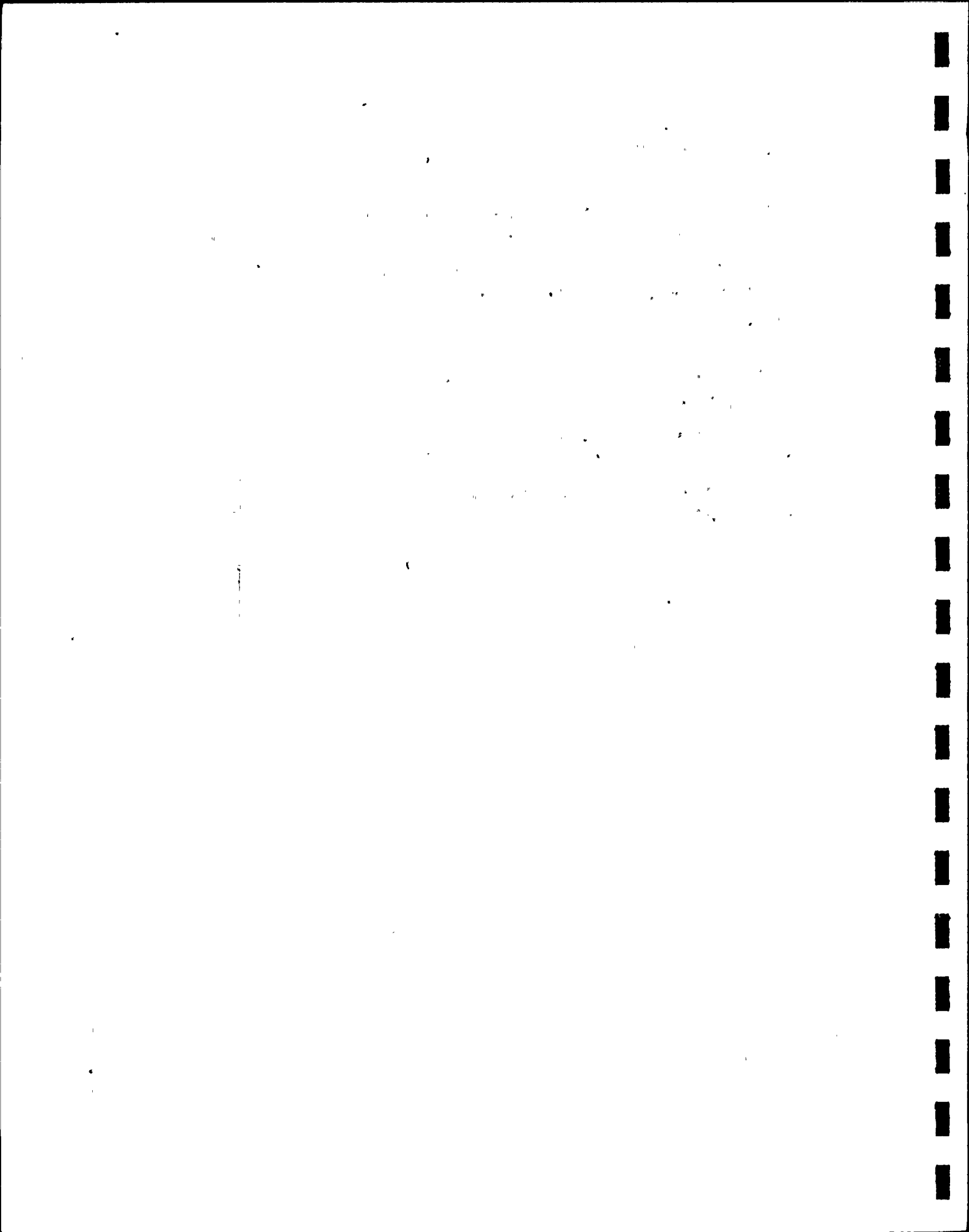


SUMMARY (cont'd)

During a cold shutdown in late January, the RCS was treated with hydrogen peroxide. Significant crud releases were observed and upon return to power operation, core dp was observed to be normal. No fuel failures were observed during the episode. In late March, the issue was considered satisfactorily resolved and the Task Forces were disbanded.

Task Force investigations resulted in the implementation of several permanent changes to plant surveillance and operating instructions. Several hardware modifications are also being pursued. In order to assess any lasting effect of the episode on fuel integrity, a fuel inspection program will be performed at the next refueling, currently scheduled for October, 1980.

In late May, 1980, Unit 1 is operating at full power and all core and fuel performance parameters are normal.



II. NARRATIVE

At approximately 0800, October 22, 1979, the Plant Nuclear Engineer observed that the Axial Shape Index (ASI), Planar Radial Peaking Factor (F_{xy}), and Integrated Radial Peak (F_r) had been steadily increasing since the previous week. Azimuthal tilt (T_q) had been holding steady at about .006. Predictions indicated that F_r and F_{xy} should experience a very slow decrease in magnitude with core burnup.

During the next three days, The Plant Staff increased surveillance on the critical core parameters from once every eight hours to once every hour and prepared local power distribution maps in order to assess the degree of local change in power distribution since October 13. In addition, a systematic review of other plant information was begun. Specifically, beginning with Cycle 4 Startup, trends of the following parameters were evaluated:

- Hydrogen Overpressure in the Volume Control Tank
- Differential pressure across Reactor Core and Reactor Coolant Pumps
- Hydrogen concentration in the Reactor Coolant System

On October 25 a package of raw core power distribution data was forwarded to Combustion Engineering (CE) for analysis in accordance with a standard core verification program performed for Calvert Cliffs by CE. At about 0800 on October 25, the measured peak linear heat rate was 10.7 Kw/ft., F_r was 1.45, F_{xy} was 1.56, T_q was about .007, and Internal Axial Shape Index was +7.6%. Out of a precautionary concern for fuel integrity, the Plant Nuclear Engineer limited reactor power such that a summation of measured power level plus the Axial Shape Index would not exceed 108%. This was a simple technique for maintaining the peak linear heat rate at or below that which had been successfully experienced through October 25.

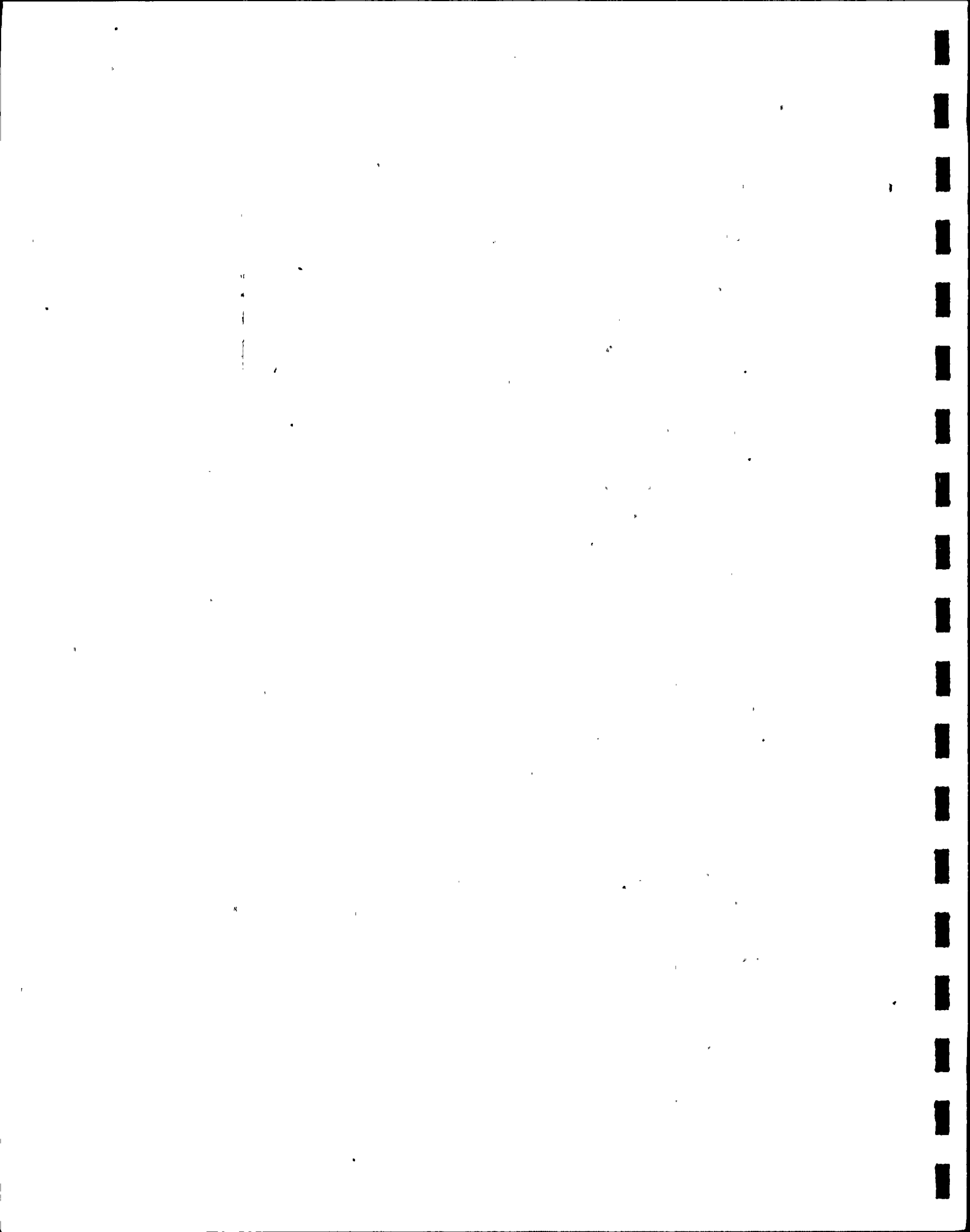
On October 26, the Plant Nuclear Engineer began a periodic transmittal of core parameter trend data to CE. See Figures II.1 and II.2.

NARRATIVE (cont'd)

On October 26, the Plant Staff suspected the cause of the increasing pressure drop across the reactor core was due to an increasing crud deposition on fuel surfaces and began a search for sources of Oxygen into the Reactor Coolant System. During this time, it was also observed that trend data indicated a lower than normal Hydrogen concentration in the Volume Control Tank. By October 29, the source of Oxygen had been identified and isolated. While Number 11 Deborating Ion Exchanger was in service (See Figure II.3), it appears that air was introduced into the purification system via the Instrument Air header. Instrument air is normally used to transfer spent resin. Apparently, two (2) valves (1-IA-234 and 1-CVC-151) leaked by their seats allowing air to be introduced into the outlet of the ion exchanger. When sampled, the ion exchanger outlet had an Oxygen concentration of 300 ppb. The ion exchangers were bypassed and the Instrument Air header drain valve (1-CVC-154) was opened and left open to ensure that the header remained depressurized; thereby precluding introduction of Oxygen into the Reactor Coolant System.

On October 27, CE verified the power redistribution observed by the Plant Nuclear Engineer. The core was experiencing a slowly increasing roll of power toward the core center and toward the core bottom. Whereas prediction did indicate a slow roll in power to the core center, the measured roll was greater than the prediction. The prediction did not indicate a roll in power toward the core bottom.

Early the week of October 29, the Plant Staff and CE concluded that the cause of the power redistribution was a crud buildup on the fuel rod surfaces, preferentially to the top of the core. The crud would contain iron and other oxidized constituents of stainless steel which would act as a mild poison to the fission reaction; and in addition, the crud may change the heat transfer characteristics across the fuel rod resulting in an increasing Doppler feedback effect. This conclusion was also consistent with a small reactivity anomaly evident in a trend of measured versus predicted boron concentration in the Reactor Coolant System. See Figure II.4.



NARRATIVE (cont'd)

On November 1, the Plant Staff and CE began a discussion of strategies for removing crud from the fuel rods. In addition, the Plant Staff began analyzing for Hydrogen at a Reactor Coolant System hotleg sample point. At no time prior to and during the observation of the core power redistribution was Oxygen observed in the Reactor Coolant System (RCS). However, as a precaution, the Hydrogen concentration in the Volume Control Tank was increased resulting in a corresponding increase in Hydrogen concentration in the Reactor Coolant System.

On November 2, the Plant Nuclear Engineer directed CE to begin a correlation of crud thickness and other characteristics with reactor power redistribution as well as a quantitative evaluation of its effect on the safety analysis.

On November 3, the Plant Chief Engineer organized a Power Distribution Task Force chaired by the Plant Nuclear Engineer and consisting of the Plant Radiation-Chemistry Engineer and the Plant Operations Engineer.

On November 5, the I&E Regional Office was informed of the Power Distribution Episode by the Shift Supervisor and also by the Plant Chief Engineer. In addition, the Plant Nuclear Engineer responded to a query from the NRC Project Manager for Calvert Cliffs. At this time, no plant technical specifications had been exceeded. The parameter closest to a limit was F_{xy}^T which was measured at 1.64. Limit is 1.66.

On November 6, CE informed the Task Force that CE's preliminary evaluation revealed the possibility of lithium concentration in the presence of local boiling in the porosities of the crud layer. Therefore, CE recommended a decrease to 80% power in order to alleviate that concern and to gain more margin. The Task Force concurred and reactor power was decreased to 80%.

NARRATIVE (cont'd)

By November 7, the strategy for removing crud had been developed. Lithium concentration would be increased slightly from less than 1 ppm to about 2 ppm in the Reactor Coolant System, thereby raising pH and creating an environment for slow dissolution of the crud layer. At this time, CE had completed their evaluation and determined that the appropriate power level for precluding local boiling in crud porosities at the hottest point in the core was 50%. CE recommended that the increase in lithium concentration in the RCS take place at that power level. The Task Force concurred.

In addition to determining the cause of and resolving the power maldistribution, a charge to the Task Force was to keep the Plant and Offsite Safety Committees informed. Beginning November 5, the Plant Safety Committee was briefed periodically and on November 8 the Task Force made a written report to the Offsite Safety Committee.

By November 8, the reactor had been stabilized at 50% power and lithium additions to the RCS had begun in order to gain and maintain the concentration in the RCS at about 2 ppm. The purification ion exchanger was put back in service. Also, CE formed a Task Force consisting of members with physics, thermo-hydraulics, materials, and chemistry backgrounds.

On November 9, Brookhaven National Laboratory (BNL) began investigation of the anomaly at the request of NRC staff. Plant data was provided BNL via CE engineers who were diagnosing the anomaly and developing a model.

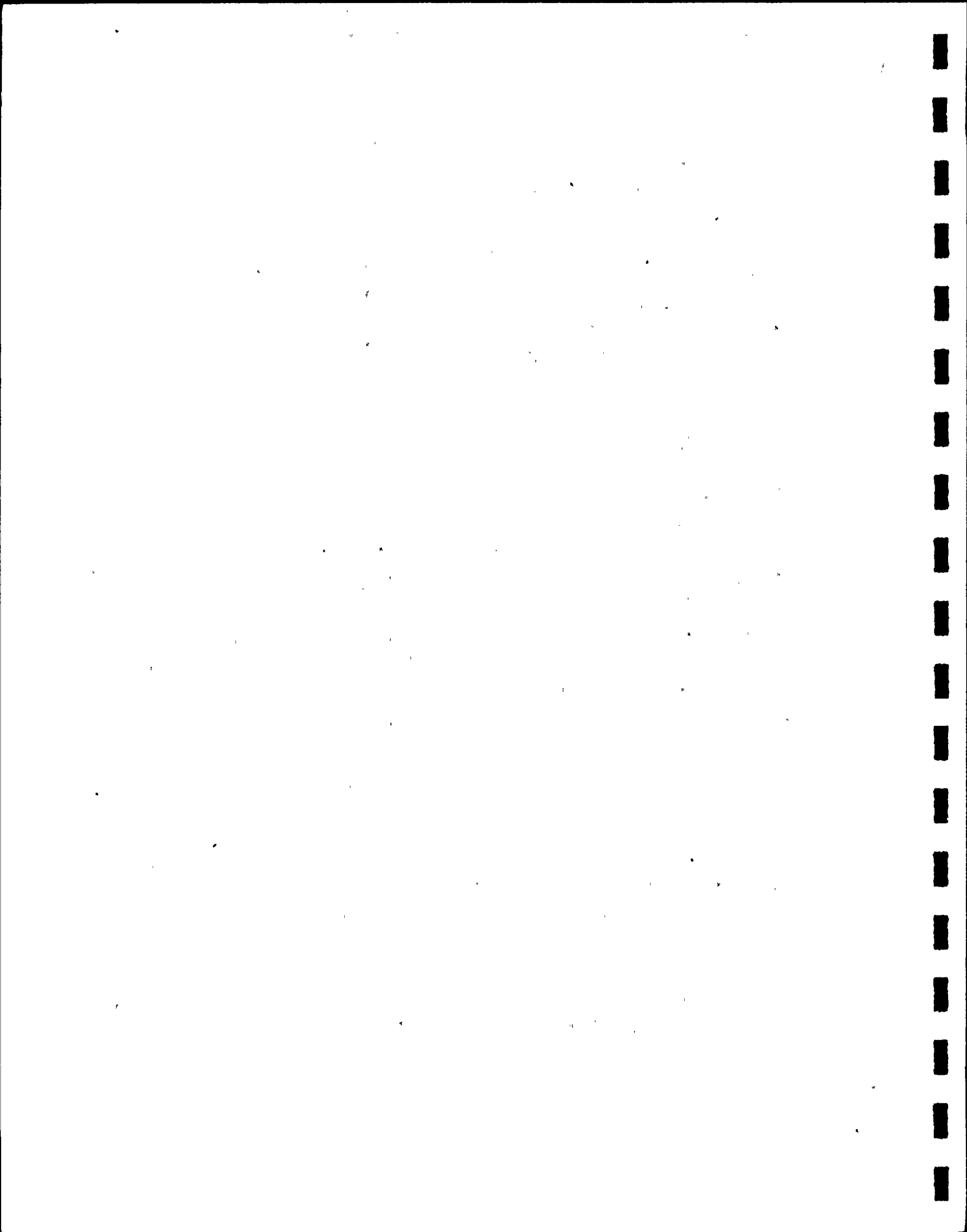
By November 17 potential causes for the anomaly other than crud had been reviewed and discarded including: broken CEA finger, mechanical flow blockage, pressurizer heater insulation, and buildup of isotope(s) with high neutron cross sections. Also on November 17, the first in a long series of reactivity (temperature and pressure as well as power) coefficient measurements were made. It yielded a larger than normal power coefficient. The other coefficients were normal.

NARRATIVE (cont'd)

By November 19, core parameters (ASI and F_{xy}) had stabilized to well within technical specification limits and core dp was steady at 14.7 psid. CE recommended a power increase to 60% for further evaluation of core parameter trends. The Task Force concurred and power was increased to 60% on November 21 after performance of another power coefficient measurement. During the next ten days, CE completed a review of the effect of the power redistribution and reactivity anomalies on the safety analysis and concluded that a conservative evaluation of the data would allow operation at 70% power. As long as core dp remained less than 15.0 psid with no discernable upward trend and other core parameters (ASI, F_{xy}) remained steady or improved, concern for fuel integrity at 70% power was minimal. On November 30, CE recommended a power increase to 70%. F_{xy} was 1.49 (down from a high of 1.64 on November 6) and decreasing, ASI was steady and core dp was 14.6 psid. The Task Force concurred in the CE recommendation and on November 30 power was increased to 70% for the purpose of additional observations and measurements at higher power level.

On December 5, another power coefficient measurement was performed and indicated an improving trend but a still significantly higher than normal value. A fifty liter millipore crud sample was also collected and sent to CE for analysis of its constituents. During the following week, contingency plans were refined for a Hydrogen Peroxide treatment to remove crud and for a fuel inspection (visual and zirc-oxide layer thickness measurements).

On December 8, 9, and 10 a series of pressure, temperature and power coefficient measurements were performed. The purpose of the pressure (void) coefficient measurement was to detect the presence of voiding in the porosities of the inferred crud layer. None was evident. However, ASI and F_{xy} values had shown significant and unpredicted increases over those values existing at the 60% power plateau. Therefore, when data collection was completed on December 10, power was reduced to 50%.

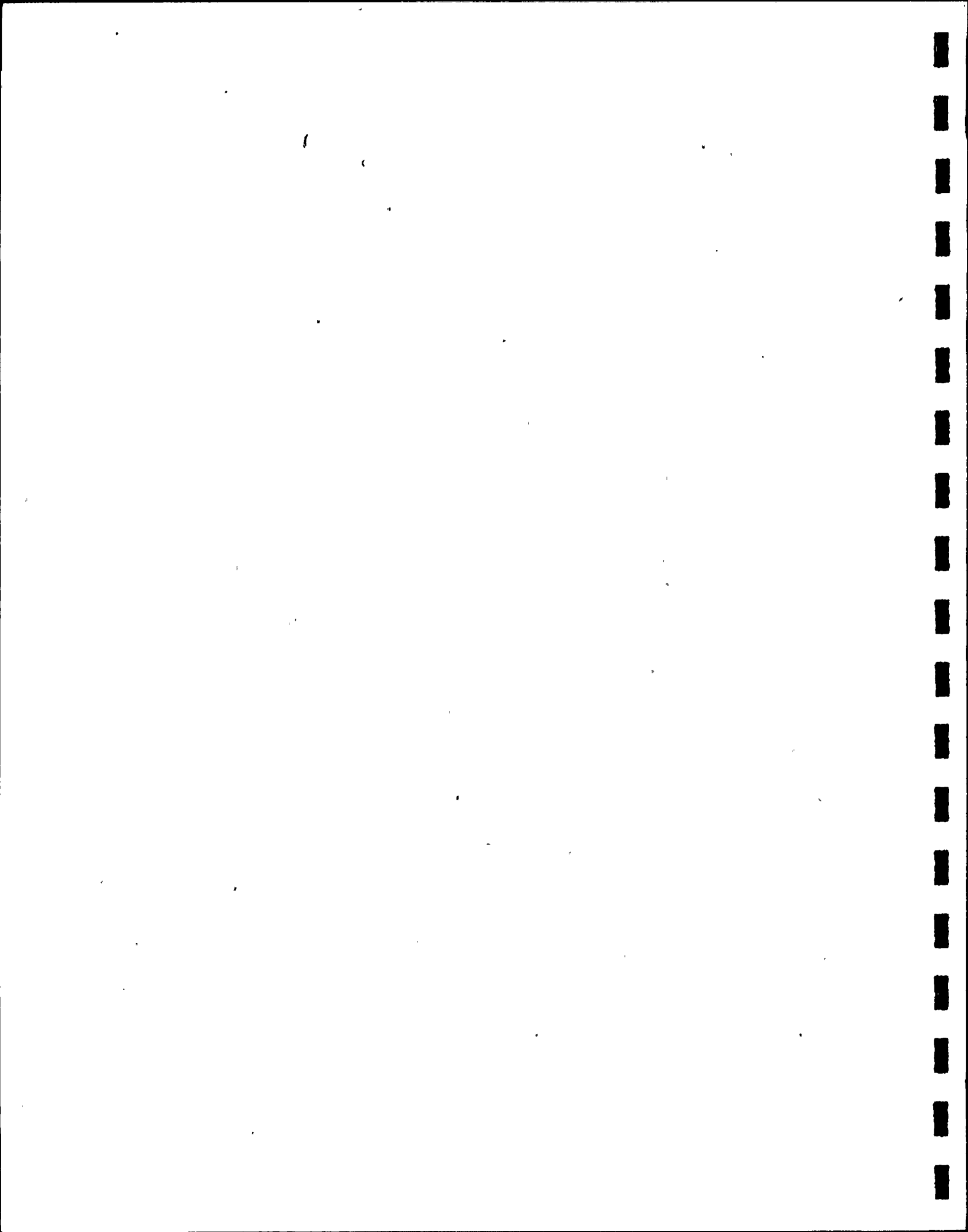


NARRATIVE (cont'd)

During the next 10 days, plans were laid and procedures prepared for a Hydrogen Peroxide treatment. RCS lithium concentration was allowed to drift toward zero in anticipation of a cold shutdown for the treatment. Meanwhile CE was evaluating the data from the 70% power plateau as well as that from reactivity coefficient measurements made on December 13, 14, 16 and 17. Several power coefficient measurements were performed on Unit 2 for comparison with Unit 1 coefficients. Unit 2's measured results were normal and as predicted.

On December 20, it was concluded that an unexplainable increasing trend in core dp over the last ten days (14.6 to 15.5 psid) probably reflected an oxidizing medium in the RCS. An oxidizing medium would make the Hydrogen Peroxide treatment ineffective. Consequently, beginning December 20, hydrazine additions were made to RCS makeup water at every addition of makeup water to the Volume Control Tank. Also, CE was not yet able to adequately model the burnup and power dependent behavior of the power maldistribution. The phenomenon was obviously more complicated than that explained by any single postulated mechanism (neutron cross section of crud, insulating effect of crud/zirc oxide, boron concentration in crud porosities, etc.). Consequently, even though F_{xy} was slowly decreasing and ASI was stable, a power increase was premature.

On December 22, it was concluded that the increase in core dp was probably due to a combination of aerated RCS makeup water and short term injections of air into purification ion exchangers during resin transfer. Procedures were changed to remove all inservice ion exchangers from service during a resin transfer anywhere in the system. This action, in combination with the hydrazine addition, coincided with a stabilization of core dp at 15.5 psid.



NARRATIVE (cont'd)

Power coefficient measurements on December 27 and January 2, 1980 continued to show an improving trend. Other core parameters as well as core dp were still stable or improving. Based on this encouraging evidence, CE recommended an increase to 60% power in order to detect any change in the power dependent behavior of the maldistribution. The Task Force concurred with the CE recommendation and power was increased to 60% on January 3.

On January 5, a power coefficient measurement at 60% power confirmed an improving trend. In addition, the power dependence of the core parameters continued to approach normal. Core dp unexplainably stepped up to 15.6 psid on December 4 but stabilized there. On January 7, this encouraging trend prompted a CE recommendation to increase power to 70% for further measurements and observation of the power dependence of core parameters. The Task Force concurred and power was increased to 70%. As a contingency, work on a full core replacement option was begun; the core replacement to consist of about half new fuel and half previously discharged fuel.

The results of power coefficient measurements on January 11 and 14 as well as observation of a near normal power dependence of core parameters at the 70% power plateau were encouraging. However, core dp was still about 15.5 psid; 1.8 psid above normal. For this reason, power was decreased to 50% on January 15 and remained there until the Unit was put in cold shutdown on January 26 for TMI related modifications. Power coefficient measurements on January 17, 18, and 19 added to the expanding data base and continued to confirm improving trends. However, core dp did not budge from 15.6 psid.

NARRATIVE (cont'd)

On January 22 NRC staff was briefed on the episode by BG&E and CE at a meeting in Bethesda. At the previous request of NRC staff BG&E also explained the procedure for Hydrogen Peroxide treatment. NRC staff declined to be an impediment to performance of a Hydrogen Peroxide treatment or to be an advocate of a fuel inspection.

On January 26, coincident with the start of cold shutdown, Hydrogen Peroxide treatment of RCS was initiated. Three Hydrogen Peroxide injections were made on January 27. Encouraging crud releases were observed. Clean up of the RCS via purification ion exchangers continued until late January 29. Calibration of the core dp sensing device was confirmed. Effect on core dp was ambiguous until the plant was returned to a hot shutdown condition on February 10 at which time core dp was measured at 14.0 psid. This improvement exceeded the most optimistic predictions. Therefore, contingency plans for continuing the decruding process by raising Lithium concentration in the RCS to 15 ppm while remaining in hot shutdown were delayed.

From February 10 through 11, a short post-shutdown zero power test program including a critical boron concentration measurement, iso-thermal temperature coefficient measurement and a worth measurement of CEA 5-1 was performed. Measured data agreed with predictions. Based on this evidence, near normal values of core parameters, and a near normal core dp, power was increased to the 50% test plateau on February 12.

During the next week, core dp slowly decreased to 13.8 psid. A power coefficient measurement on February 15 yielded near normal results. Other core parameters were near normal. Based on this encouraging evidence, power was increased to 70% on February 19.

NARRATIVE (cont'd)

Power coefficient measurements on February 21 and 22 continued to show improvement. Other core parameters and core dp were normal. There was still no evidence of fuel failures associated with the episode. A conservative treatment of the effect of the episode on the safety analysis justified 100% power operation. Out of a concern for any lingering effects of the episode on fuel integrity power was increased to 85% on February 23 for an interim period and then to 100% on March 6.

After two weeks at 100% and with all symptoms of the power distribution episode gone, on March 21 the Task Force concluded with CE's concurrence that special surveillance in effect during the episode could be relaxed toward normal. In addition, work on a core replacement option was terminated and Lithium concentration in the RCS was allowed to drift down to normal operating range. Lessons learned were incorporated into plant procedures and the Task Force was disbanded.

On March 21, core parameters including core dp were as predicted for an unperturbed core.

Power Level	2700 MWth
Core dp	13.7 psid, steady
F_{xy}	1.425, slowly decreasing
ASI	+.01, steady (unrodded core)
Local Power Distribution	- normal
Reactivity Anomaly	- near zero ppm boron

The fuel performance indicators were also normal.

I 131	$\sim .003$ <i>wt</i> /cc
I 133	$\sim .03$ <i>wt</i> /cc



NARRATIVE (cont'd)

On May 27 the nominal values of those same parameters were:

Power Level	2700 MWth
Core dp	13.6 psid, steady
F_{xy}	1.415, slowly decreasing
ASI	+.01, steady (unrodded core)
Local Power Distribution - normal.	
Reactivity Anomaly - near zero ppm boron	
I - 133	$\sim .003$ <i>sk/cc</i>
I - 133	$\sim .03$ <i>sk/cc</i>

Figures II.5 and II.6 trend power level, core dp, F_{xy} and ASI from September 1979 through May 1980.

FIGURE II.1

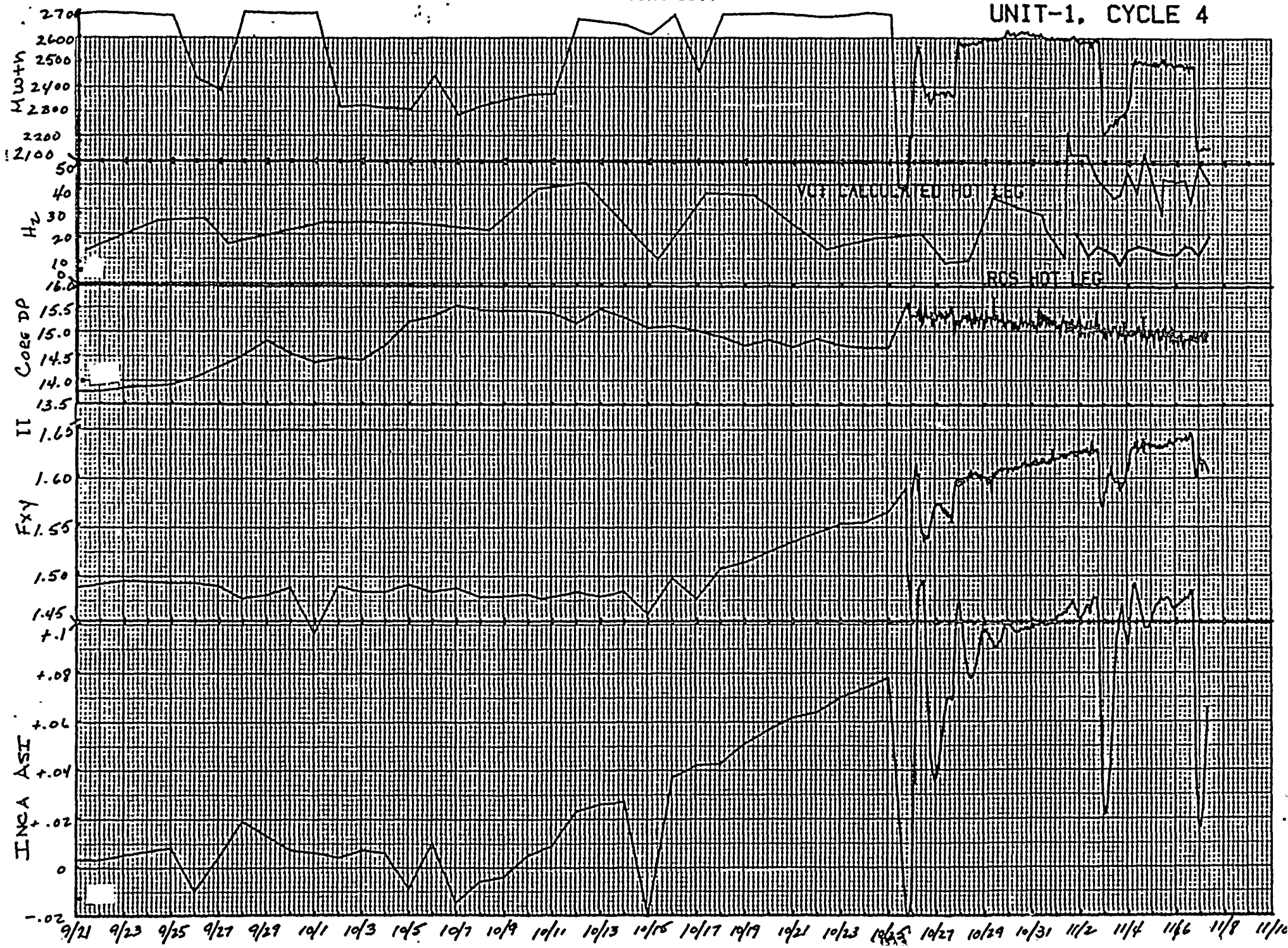
CORE PARAMETERS
UNIT-1, CYCLE 4

FIGURE II.2

CORE PARAMETERS
UNIT-1, CYCLE 4

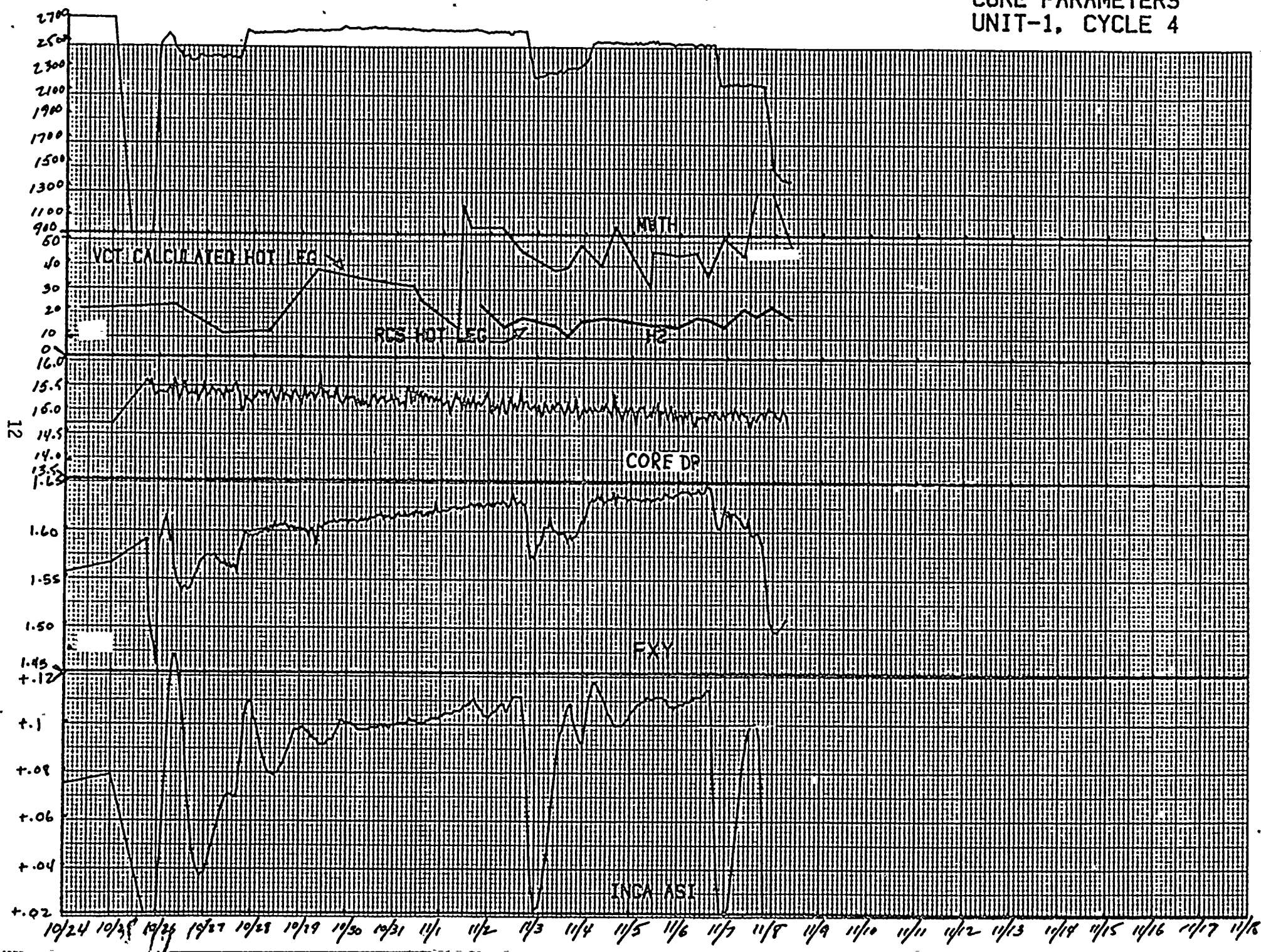


FIGURE II.3

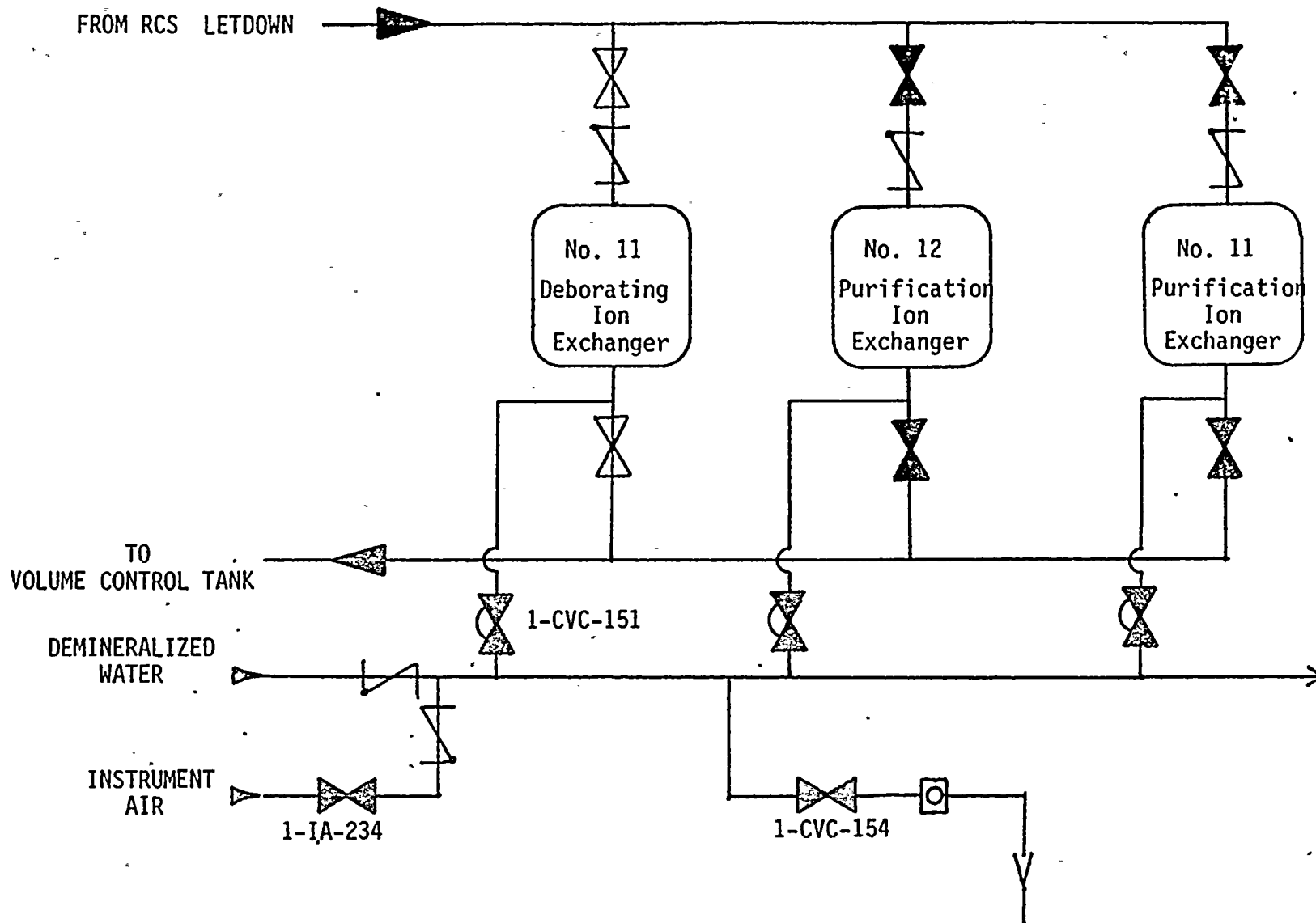


FIGURE II.4

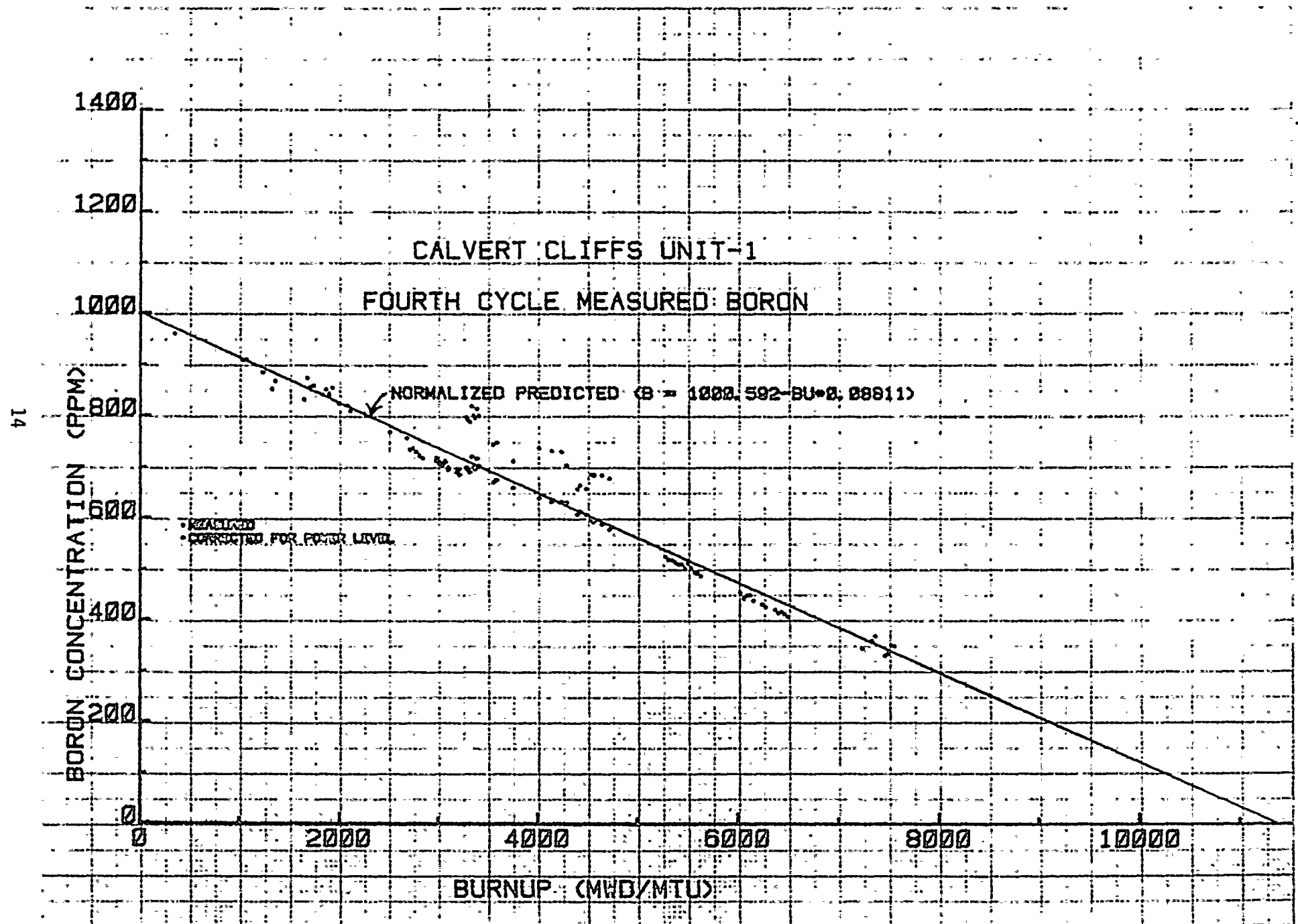
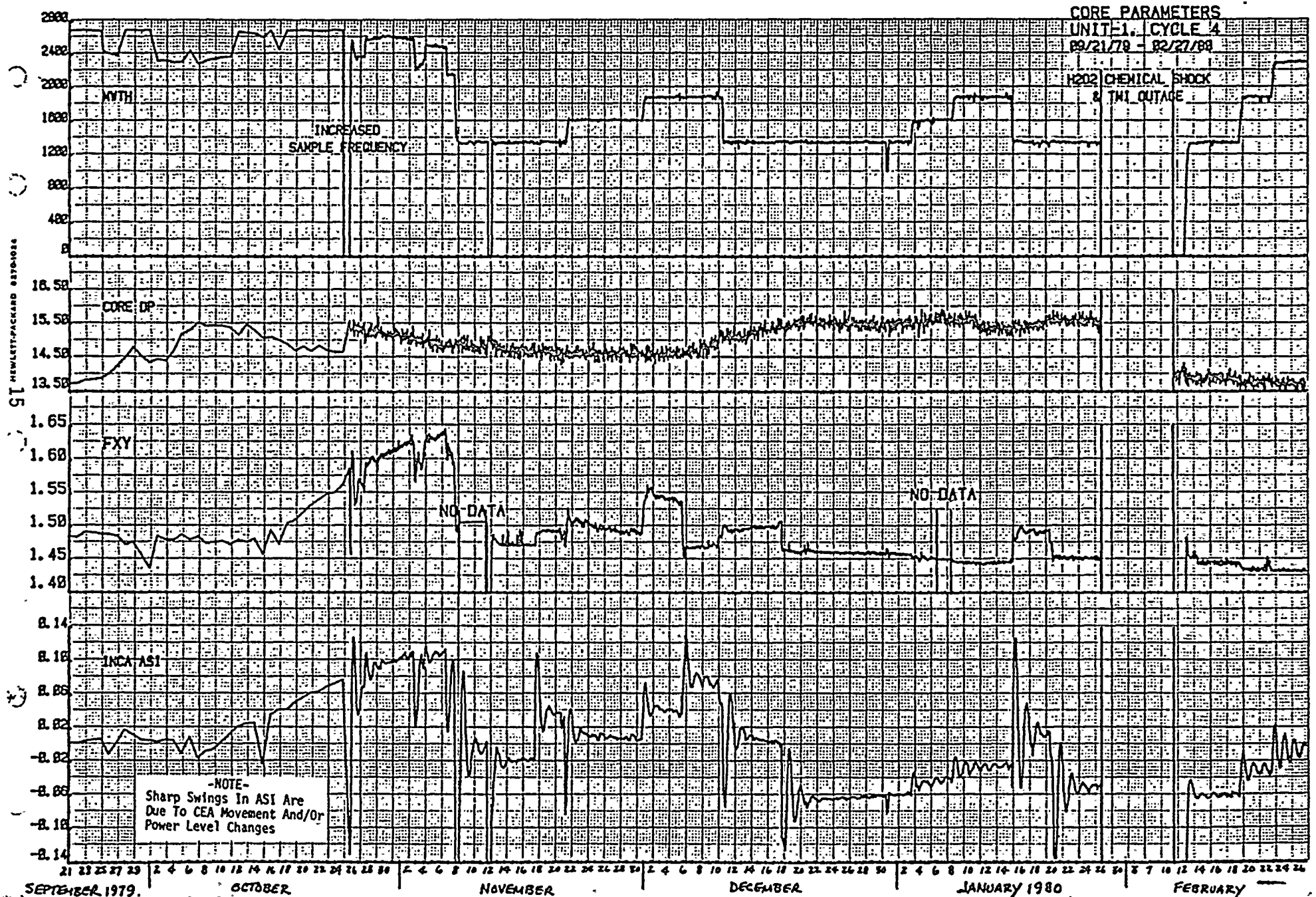


FIGURE II.5



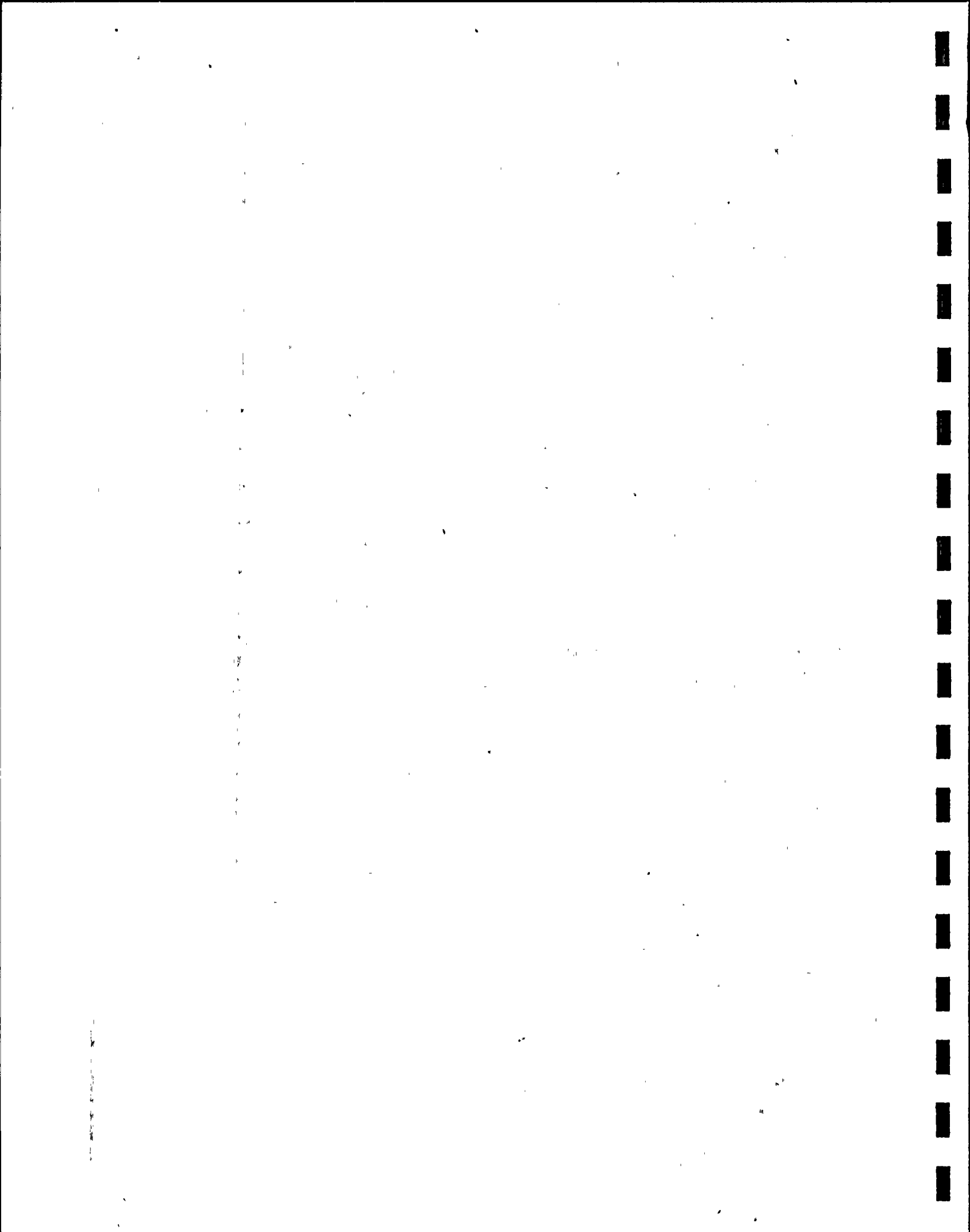
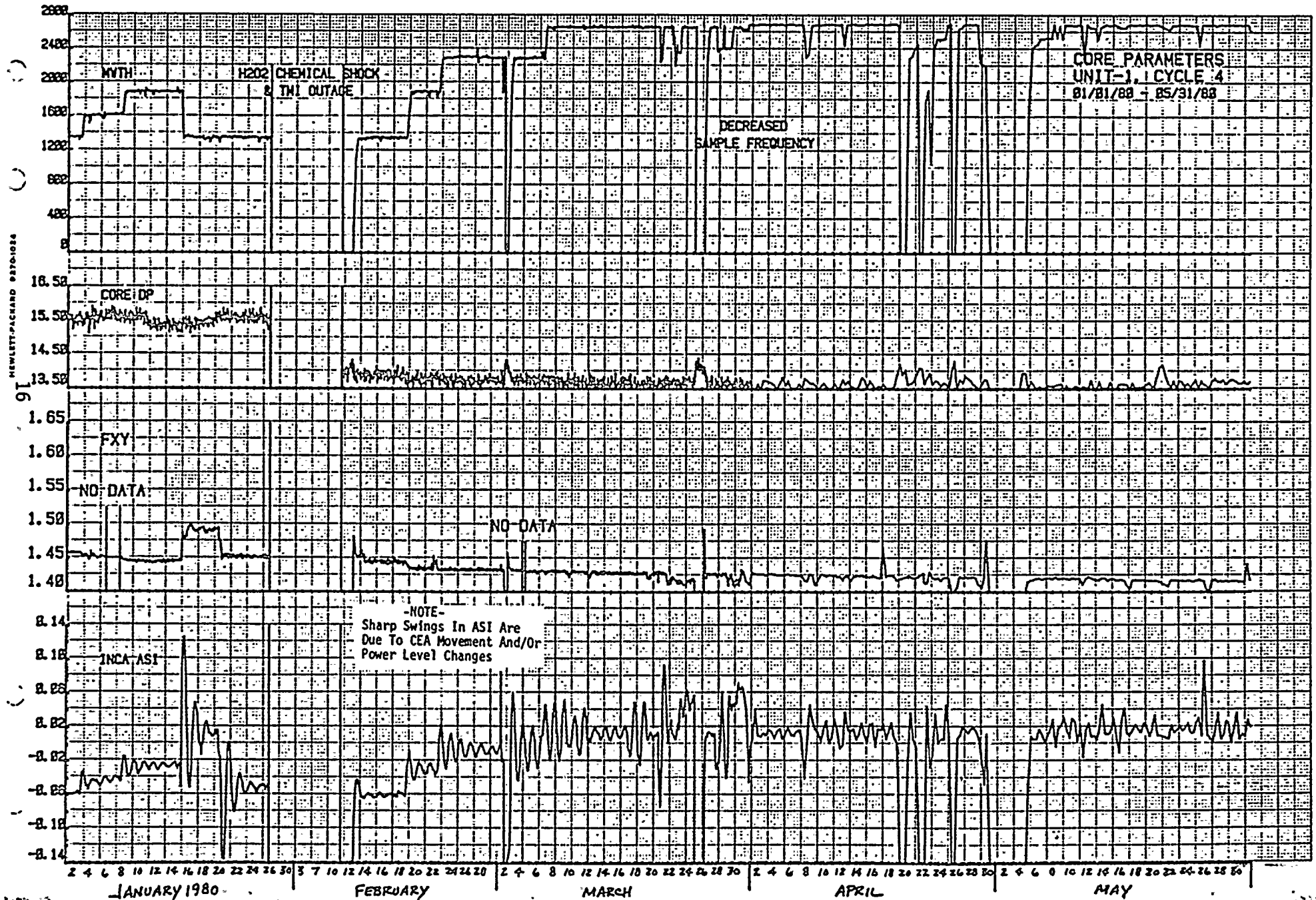
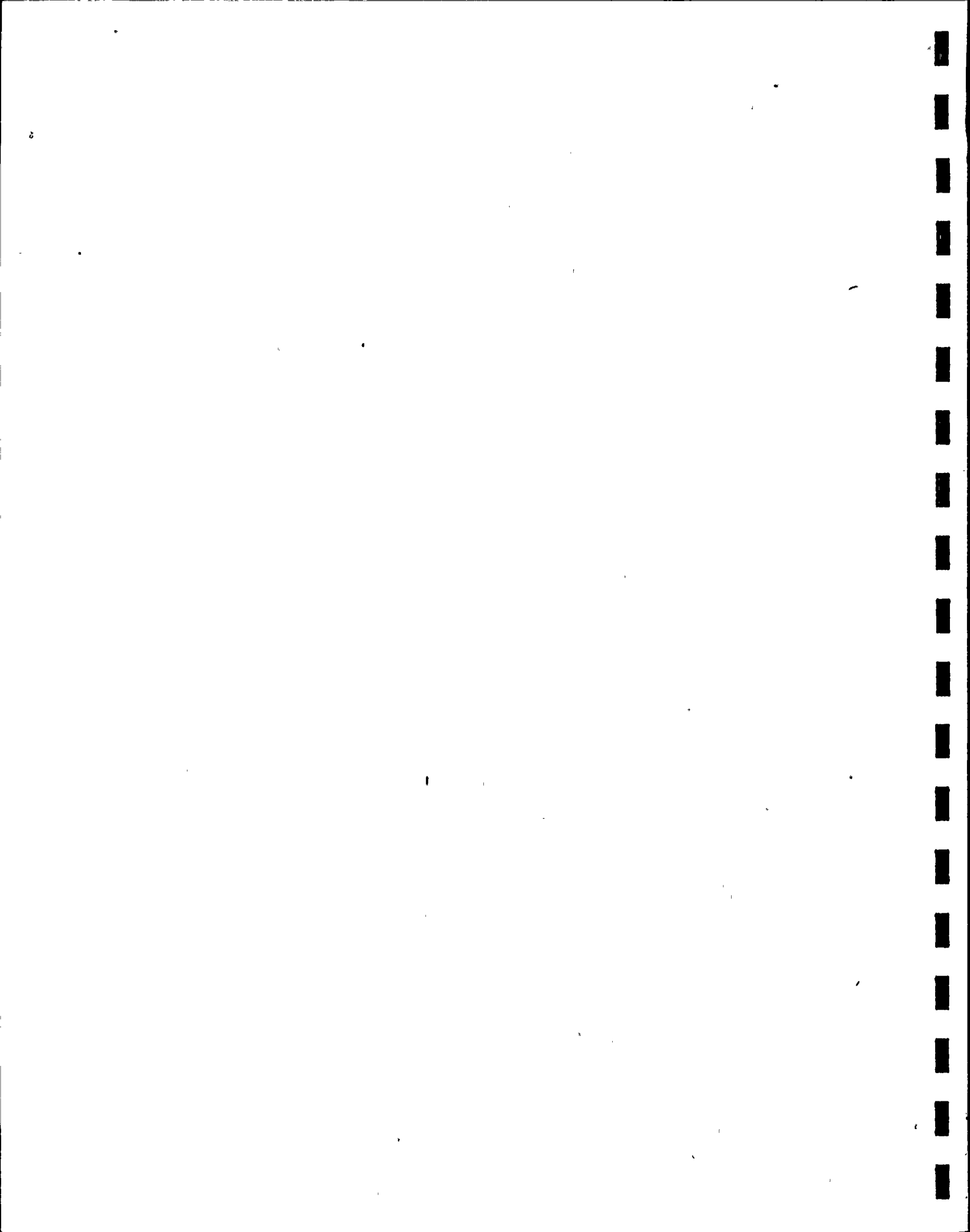


FIGURE II.6





III. CORE PARAMETER OBSERVATIONS AND DIAGNOSTICS

A. Physics Analyses

Two types of physics analyses of this event were conducted. The first analysis was a simulation of the spatial perturbation required to produce the observed effects. The second analysis involved core follow using a three-dimensional ROCS model to quantify the departure of various core parameters from their expected values and is presented below.

1. Core Follow Models and Results

A three dimensional coarse mesh nodal model (ROCS) was used for all analyses. Two sets of cross-sections were used. One set was based on the CEPAC spectrum code and had been previously used in the design of this reactor cycle. The other set was based on the assembly integral transport code DIT. This latter model better predicts reactivity levels and radial power distributions and was used more extensively in this analysis.

Each major parameter characterizing the core is described, and comparisons between measured and calculated values is given.

a. Reactivity

A measure of the core reactivity is given by the soluble boron concentration. As the anomaly progressed, the core reactivity decreased, requiring a reduction in the soluble boron concentration of about 40 ppm at full power.

If this reduced boron concentration is input to a calculational model which does not contain any additional poison, the calculated reactivity will be high by an amount equal and opposite to the additional poison worth.

8

The results of such calculations are given in Figure III.1. Prior to the event, 13 values of boron concentration taken at full power were used to define the unperturbed reactivity level. During the event (10/24/79 to 12/3/79) a strong power dependence of the reactivity can be seen. Translated into a power coefficient, this bias is equal to $[-.85 \times 10^{-4} \Delta p / \% P]$ which is almost as big as the unperturbed power coefficient itself. Since the measured boron concentrations are taken after 2-3 days of steady power operation, one must attribute a time constant of less than or equal to 1 day (3 time constants to reach equilibrium) to the power dependence. After 12/23 the reactivity level returned to normal.

b. Axial Shape Index

The measured axial shape index (ASI) is displayed as a function of power level in Figure III.2. Following an increase of the ASI during 100% power operation between 10/10 and 11/6, a linear variation with power can be seen, except for a small displacement following a four pump loss of flow incident on 11/12/79. During recovery, the ASI became strongly negative. This is a consequence of having accumulated more burnup in the bottom half of the core during the previous two months, thus shifting the power to the top after recovery. The difference between measured and calculated ASI is given in Figure III.3. Again a linear dependence of the perturbation with power level can be seen. The difference in ASI during recovery is somewhat misleading because the core follow model does not account for the distorted burnup distribution. Nevertheless, the change in ASI between 12/3 and 12/23 is an indication of partial recovery. 18

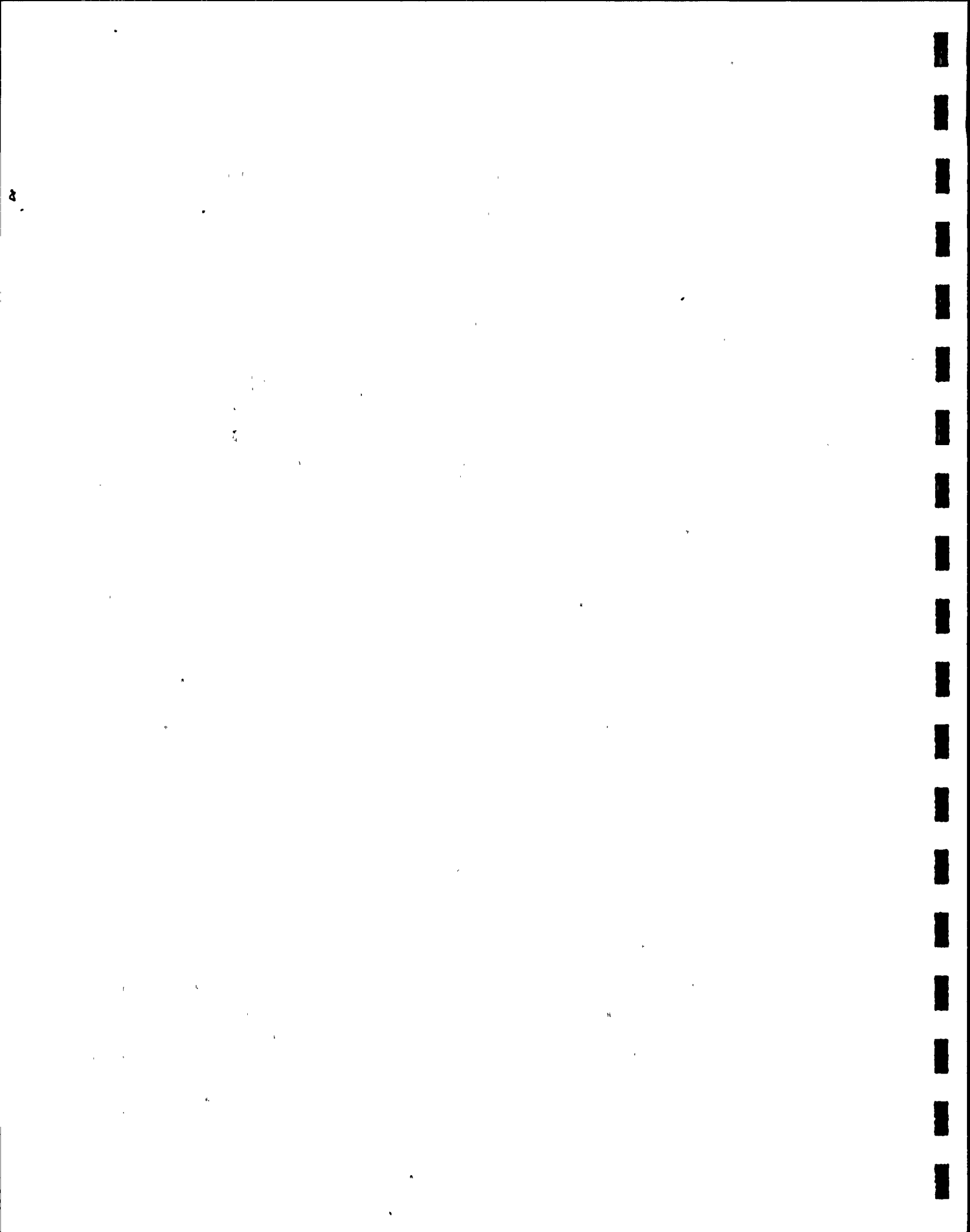
c. Radial Power Distribution

The power distribution distortion during the event was characterized by a shift to the bottom of the core as well as a shift to the core center. The amplitude of the radial shift was monotonic with core height suggesting that most of the reactivity defect was associated with the upper, outer region of the core. Therefore, the maximum radial peaking factors were located near the top, in the region covered by the fourth level of Rhodium detectors.

Two quantities were used to characterize the radial distribution, i.e., planar radial peaking factor, F_{xy} , and gross radial shift amplitude.

The evolution of F_{xy} versus power level is given in Figure III.4. The comments made about ASI also apply to F_{xy} .

The measure of the gross radial shift is depicted by the ratio R of predicted to measured power in the nine central assemblies. Thus $1-R$ represents the fractional difference between measured and predicted power at the core center. If $1-R$ is positive, the measured power is higher than predicted in the central region. The evolution of $1-R$ is shown at 80% and 20% of core elevation in Figures III.5 and III.6, respectively. At the upper elevation, values as large as 12% can be seen. There is also a positive correlation with power level. At the lower elevation, the trends are too small to be significant, indicating no radial perturbation at the first level of Rhodium detectors.



d. Power Coefficients

Measured and predicted power coefficients are given in Figure III.7.⁴ During the event, the measured coefficients were about 0.30 to $0.40 \times 10^{-4} \Delta\rho/\%P$ larger than the predicted values, which further confirmed the anomaly in power dependent reactivity. The difference between predicted and measured power coefficients is given in Figure III.8, together with the bias and uncertainty bands defined for this parameter from the analysis of a broader data base. During November and early December, the difference was substantially larger than the one-sigma uncertainty, and marginally larger than the K-sigma uncertainty. A deviation in power defect of 0.175% $\Delta\rho$ is obtained by integrating the average error in power coefficient ($.35 \times 10^{-4} \Delta\rho/\%P$) between 50 and 100% power. This error is about 45% of the reactivity defect displayed in Figure III.1 (0.4% $\Delta\rho$) based on steady state boron concentrations at various power levels. Thus, the power coefficients confirm the direction, but not the magnitude, of the reactivity anomaly. Two scenarios can be proposed.

- (1) The power coefficient is affected by a phenomenon having a very short time constant, and in addition the steady state reactivity is also affected by a phenomenon having a longer time constant (days).
- (2) Both power coefficients and steady state reactivities are affected by the same phenomenon, which has a time constant of about one hour. The power coefficient measurement, being performed over a period of half an hour, is taken during the reactivity transient and is only affected by about half of the reactivity shift.

Benchmark measurements were also performed on Calvert Cliffs Unit 2, Cycle 3 to establish the value of the power coefficient in an unperturbed core under similar conditions of burnup and power level. These results, given in Figures III.7 and III.8, show no significant departure from the prediction.

2. Burnup Distribution Perturbation Model and Results

As a result of operation with a distorted power distribution, the bottom of the core accumulated more exposure and the top less than would have occurred under normal operating conditions. After return to normal operation, the ASI was expected to be more top peaked because of the reduced burnup in this region than would have been the case without the power distribution anomaly. This effect was assessed in order to determine what constituted "normal operation". In order to model the effect of the actual fuel burnup distribution, the ROCS burnup and fuel isotopics were adjusted to be consistent with the measured burnup distribution at 4120 MWD/T (12/25/79), the date at which the core seemed to have recovered from the anomaly.

This adjustment was made as follows:

For each incremental burnup value, one can calculate the change in any isotopic concentration N . In other words, the quantity

$$\frac{\Delta N}{\Delta Bu}$$

was calculated for each depletable isotope for each node in the ROCS model. This derivative term was multiplied by the difference in accumulated burnup over Cycle 4 between CECOR and ROCS. For each isotope at each node an incremental concentration was calculated by:

$$\Delta N = \frac{\Delta N}{\Delta BU} \{ (Bu - Bu (BOC))_{CECOR} - (Bu - Bu (BOC))_{ROCS} \}$$

in which $(Bu - Bu (BOC))_{CECOR}$ is the nodewise burnup accumulated during Cycle 4 in CECOR and $(Bu - Bu (BOC))_{ROCS}$ is the same quantity for ROCS. ΔN was then added to the ROCS concentration file. The correction was equivalent to about -300 MWD/T for the top half of the core and +300 MWD/T for the bottom half of the core.

Using this modified concentration file, the core follow depletion was repeated for the period of 12/23/79 to 1/24/80. As expected, the quantity most sensitive to this change was the ASI which became 0.07 more negative. The difference between the measured shape index and the shape index calculated using the updated burnup distribution is given in Figure III.9. A difference of .05 between measured and predicted ASI is now obtained, which might suggest that the power-dependence of the perturbation had disappeared by 1/24/80, but that a residual fixed perturbation remained. One must also consider that the correction to the burnup distribution assumes that CECOR has accumulated the correct exposure over Cycle 4. This correction did not take into account CECOR measurement uncertainties in instrumented assemblies or CECOR synthesis uncertainties in uninstrumented assemblies.

The effect of the modified burnup distribution on the radial power distribution is not as strong. At the 80% core elevation, it produced a 1% change in radial shift (Figure III.5) and at 20% core elevation, the effect was negligible.

This correction to the burnup distribution should be considered as giving a more qualitative rather than quantitative assessment of the post-event power distribution. An assessment as to whether the core has recovered should not be based on the ASI alone, but upon the entire range of measured data.

3. General Physics Conclusions

In conclusion, a strong perturbation took place between September and December, 1979, which affected many physics parameters of the core. After a slow buildup during October, a strong power dependence of the perturbation was observed in November. This power dependence has a time constant no greater than a few hours as evidenced by the rapid changes in power distributions following a change in power level and by the increased measured power coefficients.

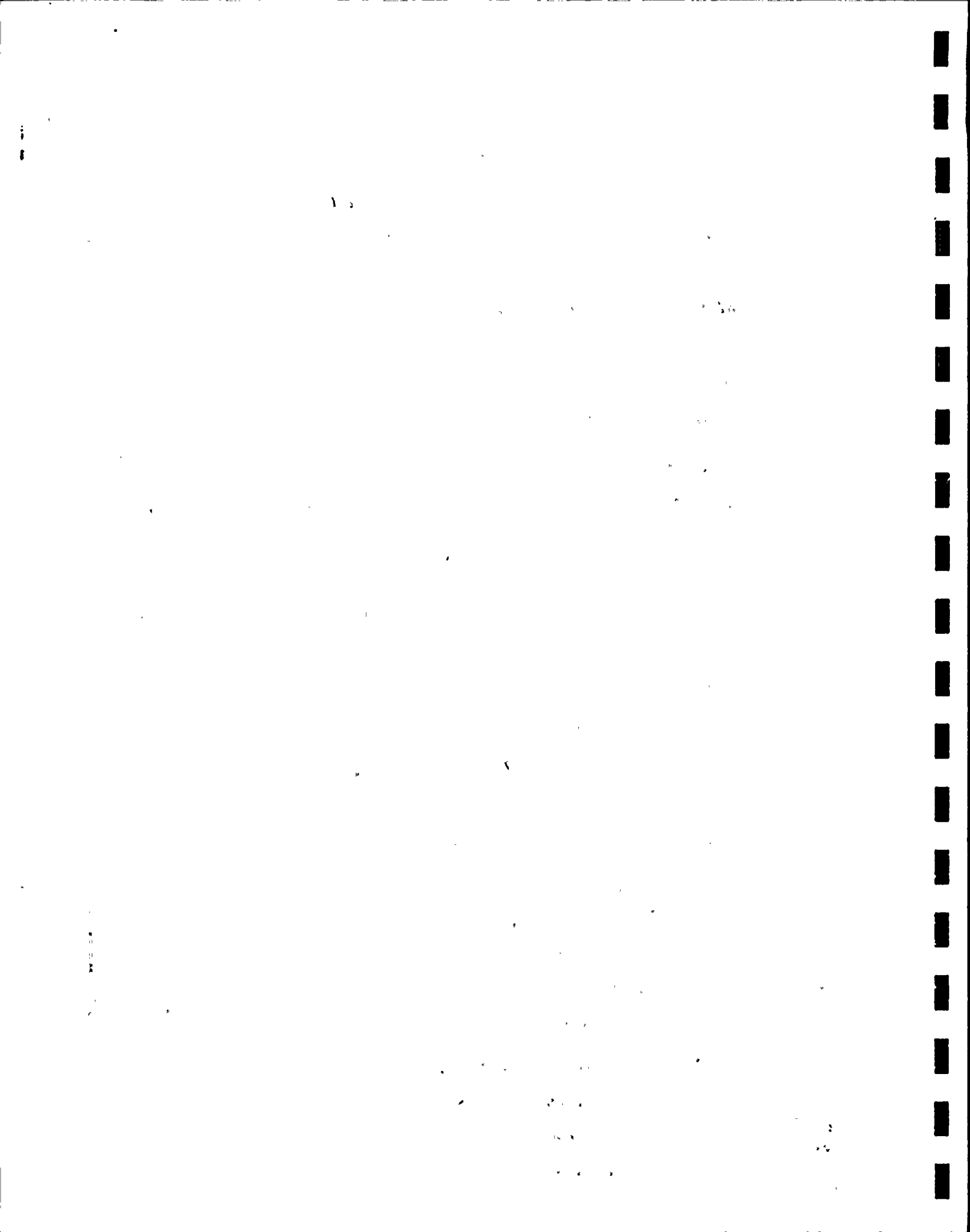
In mid December a strong recovery of all the physics parameters discussed above took place, leaving only a residual bias to the ASI and the power coefficient.

B. Core Differential Pressure

The core differential pressure (dp) history from 9/21/79 to 1/22/80 is illustrated in Figure III.10. In general, the data are consistent with alternating periods of increasing and decreasing flow resistance which may be the result of crud formation, migration or changes in surface roughness in both the reactor core and in the steam generators. The core dp remained elevated above a normal value of about 13.8 psid by as much as 1.8 psi during the September to January period, and, except for downward "spikes" in early and late October, the general trend was one of increasing core dp throughout the period.

Two points should be emphasized:

- (1) During the peak of the physics anomalies (roughly the period from late October to early December) the core dp anomaly was at its minimum value, running about 0.8 to 1.0 psi above normal; however, as dp increased during December and January to a maximum value of 1.8 psi above normal, the physics anomalies were apparently disappearing.



Although it is true that core dp may be related to frictional characteristics of the crud surface as well as to the amount of crud, the opposing trends of dp and physics anomalies must be regarded as evidence against a reactivity effect model which depends directly on the thickness of a crud layer.

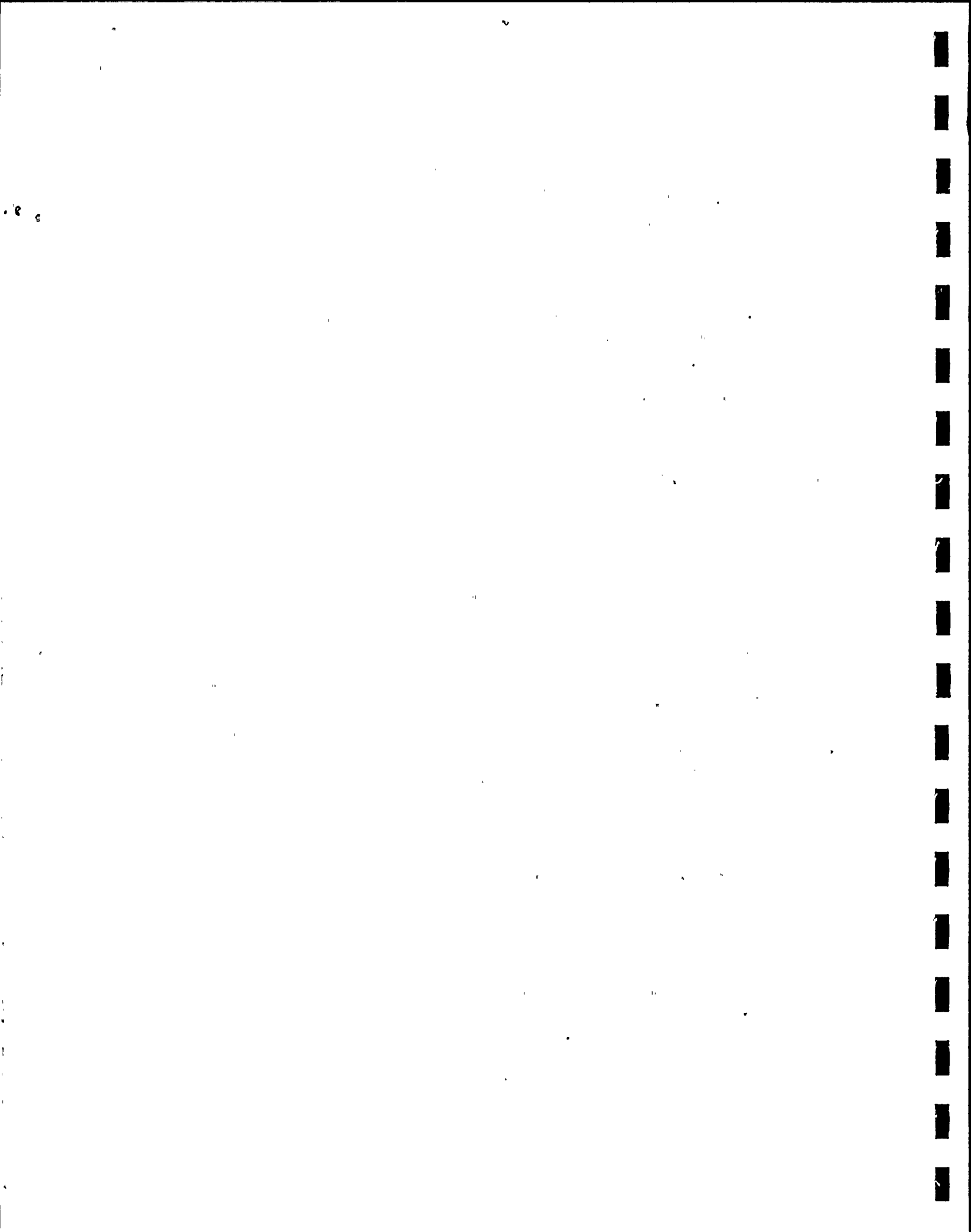
- (2) The initial rise in dp, from about 9/21/79 to 10/8/79 was quite rapid relative to some crud formation mechanisms which are thought to require months. This initial rise in dp was equal to the maximum dp anomaly observed at any time during the September-January period.

C. Temperature Distribution

In-core thermocouple (T/C) indications have been examined for several periods for any evidence of crud effects. Typical results are shown in Figures III.11 and III.12 since power levels and power distributions were quite different from day to day during the anomaly, temperature rises indicated by the T/C's are normalized by the predicted temperature rises in the assemblies in which the T/C's were located. The figures show differences in this normalized parameter between several selected pairs of dates.

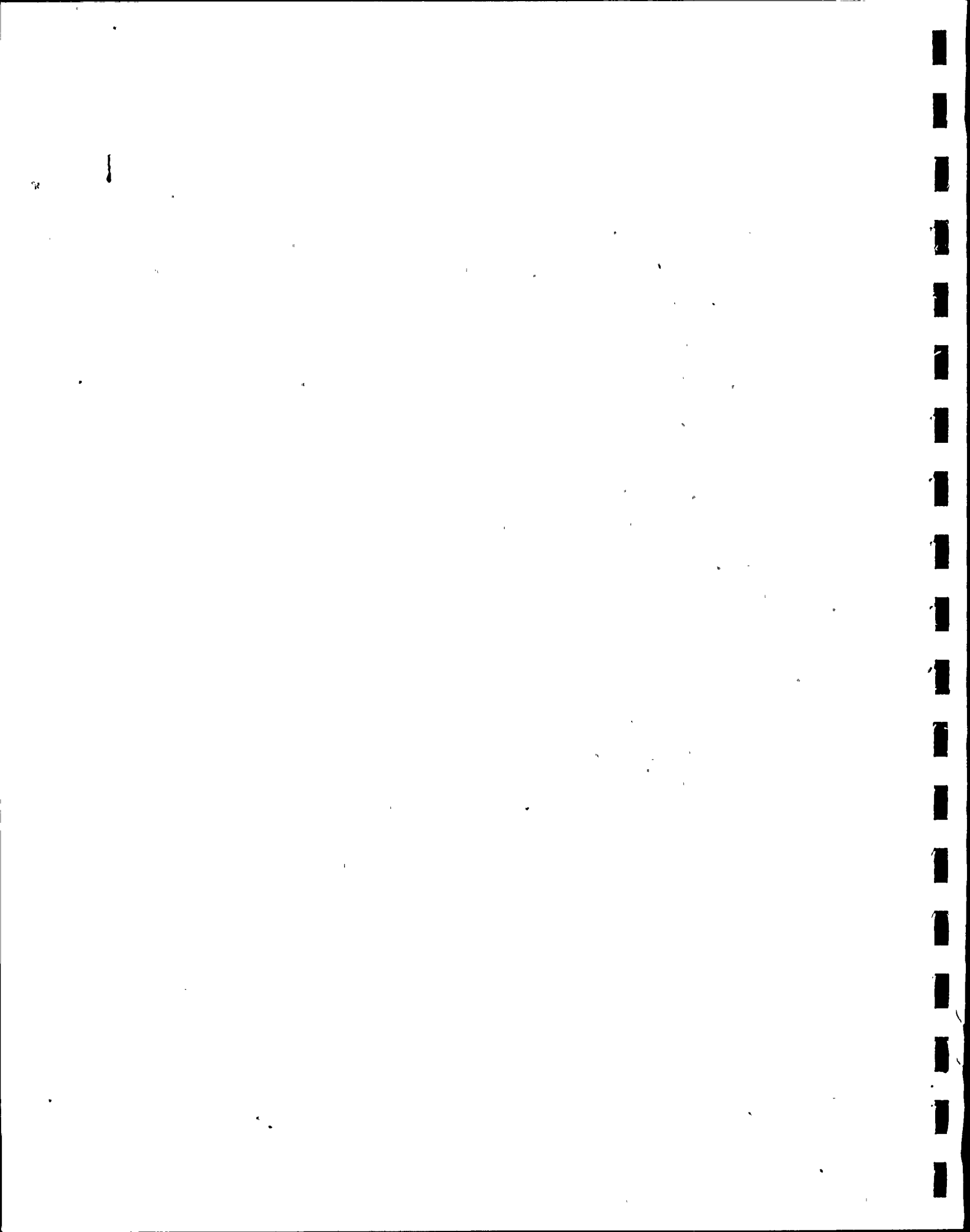
Examination of other T/C data similar to that illustrated in Figures III.11 and III.12 indicates that there was a characteristic change in T/C behavior between 9/7 and 9/14 and that this changed behavior persisted to at least 1/5/80. Temperature distributions obtained on or after 9/14 were essentially invariant. However, when temperature distributions prior to 9/14 are compared to distributions obtained on or after that date, the latter temperatures are seen to be systematically higher, typically by 5 to 15% of the assembly ΔT . This increase was consistent with a reduction in guide tube flow in the instrumented fuel assemblies, presumably due to crud formation.

A small fraction of the temperature anomaly had disappeared by 1/25/80. Following the Hydrogen Peroxide treatment, further improvement, but not a return to normal, was noted.



Several points should be emphasized with respect to T/C indications:

- (1) The T/C indications evidencing crud increased in advance of either core dp or physics indications of crud, that is, in late August as opposed to September or October; this is evidence that crud was forming at this early date.
- (2) There does not appear to be any systematic distribution of temperature increase or decrease within the core which would indicate preferential crud formation in either the periphery or the center; this is probably evidence that a small amount of crud in guide tubes and/or instrument thimbles is enough to cause the maximum observed ΔT change, with a "saturation" effect applying to any further crud formation.
- (3) The T/C readings, like the core dp indications, appear to be larger after the peak of the physics anomaly, i.e., from early December to early January. This is probably evidence of further crud shifting in the core at this later time.
- (4) T/C's in the Calvert Cliffs Units have been unreliable during normal operation in the sense that absolute values are not predictable from a knowledge of the core operating conditions only. Significant biases due to unknown causes apparently exist. Thus, T/C evidence must only be interpreted as indication of a trend.



D. Postulated Mechanisms

Many potential mechanisms were evaluated. It was concluded that the primary contributions may come from the poisoning effect of crud and boron, with a contribution from Doppler due to an increase in fuel temperature. All these mechanisms assume that crud deposition occurred preferentially in the upper peripheral region of the core. Crud deposition may induce local boiling, increase clad oxidation rate, increase fuel temperatures and increase local concentrations of boron.

The physics calculations defined the order of magnitude of the effects required to match the observed core power distribution during the anomaly. It was concluded that the poisoning effect was greatest in the outermost region of the core and a maximum in the upper portion of that region. In order to explain the physics observations at 100% power, it is necessary to invoke poison concentrations at this axial location of at least $\approx 80 \text{ mg/cm}^2$ of crud (25% Ni, 48% Fe, 27% O) on the cladding or a plating of more than $0.05 \text{ mgB}_{\text{nat}}/\text{cm}^2$ on the cladding or an increase of more than 1800°F in the fuel average temperature, or some combination of these mechanisms.

The main conclusions reached were:

The observed physics anomalies were almost certainly related to the presence of an abnormal amount or type of crud in the core. This is supported by the measured high core differential pressure.

It is very unlikely that the physics anomalies were caused solely or even predominantly by fuel heat up and associated Doppler effects. It is difficult to conceive of a mechanism which substantially increases the fuel temperature without an associated increase in cladding temperature. Cladding temperature increases of the required magnitude would have caused the fuel rods to fail through excessive oxidation, yet no failures were observed.

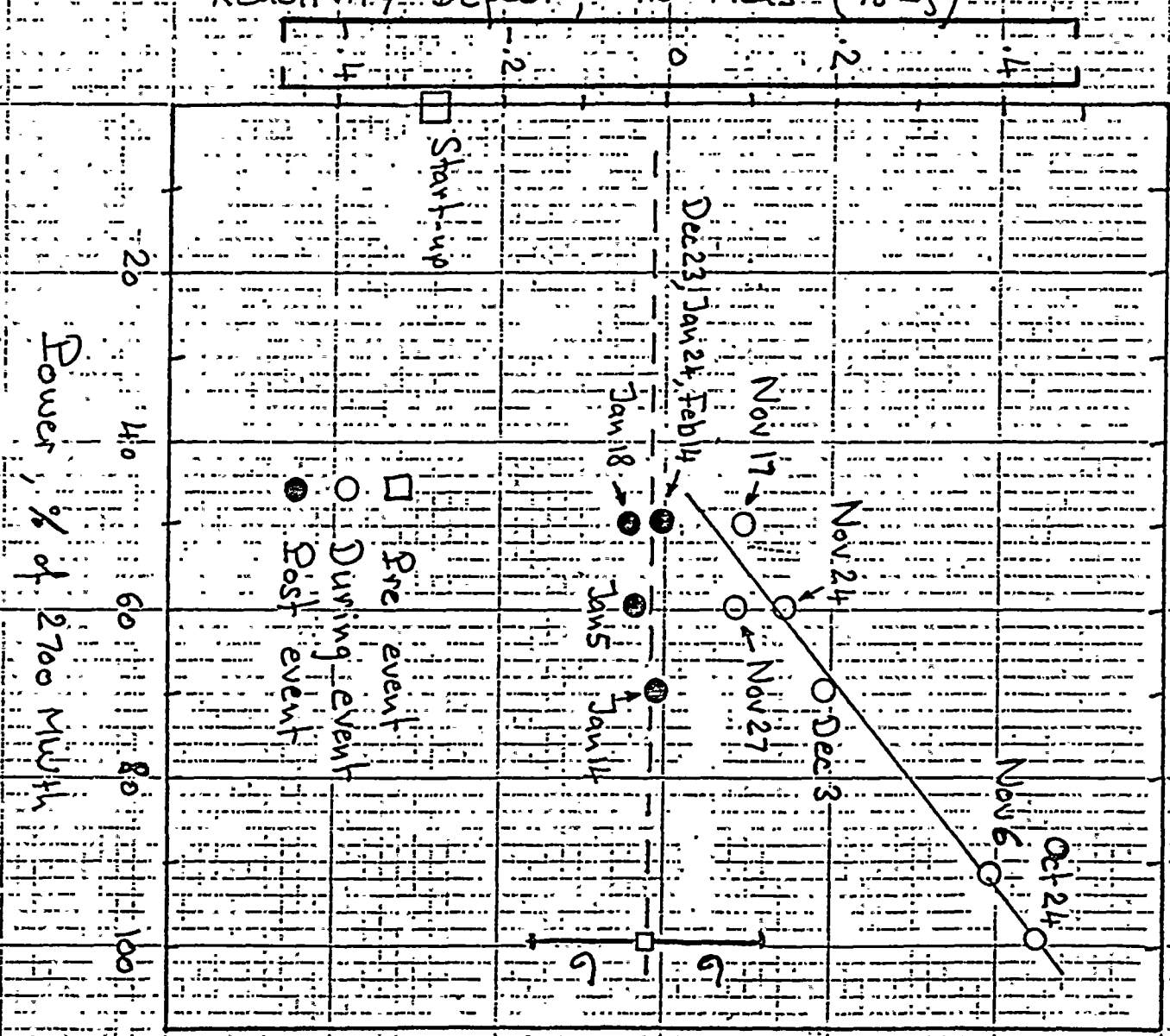
A combination of crud-related mechanisms which could have produced the observed anomalies includes the poisoning effect of crud itself, boron deposition in the crud both under boiling and non-boiling conditions, fuel heat up due to oxide formation, and the thermal insulating effect of crud.

In the postulated scenario boron concentration in the crud provides the major contribution to the physics anomaly. However, this requires very rapid boron migration into and out of porous crud. There is no known independent evidence for such a phenomenon. Similar neutronics effects have been observed in other reactors. These anomalies were ascribed to a mechanism involving crud (but not boron) by which the power-reactivity relationship was affected. The details of this mechanism are unknown.

Calvert Cliffs I Cycle 4

Reactivity Defect vs Power Level

Reactivity Defect, Calc - Meas ($\% \Delta \rho$)



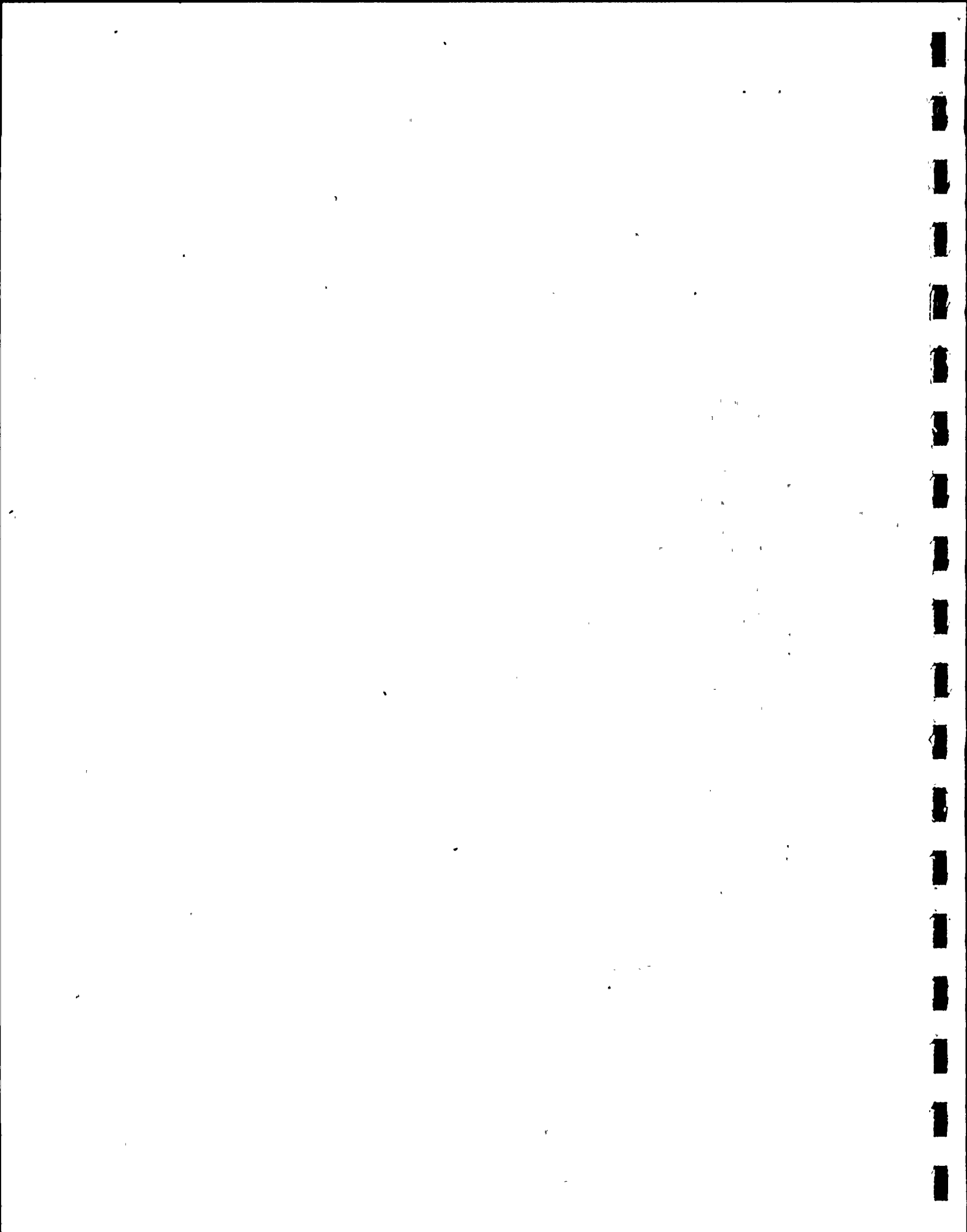
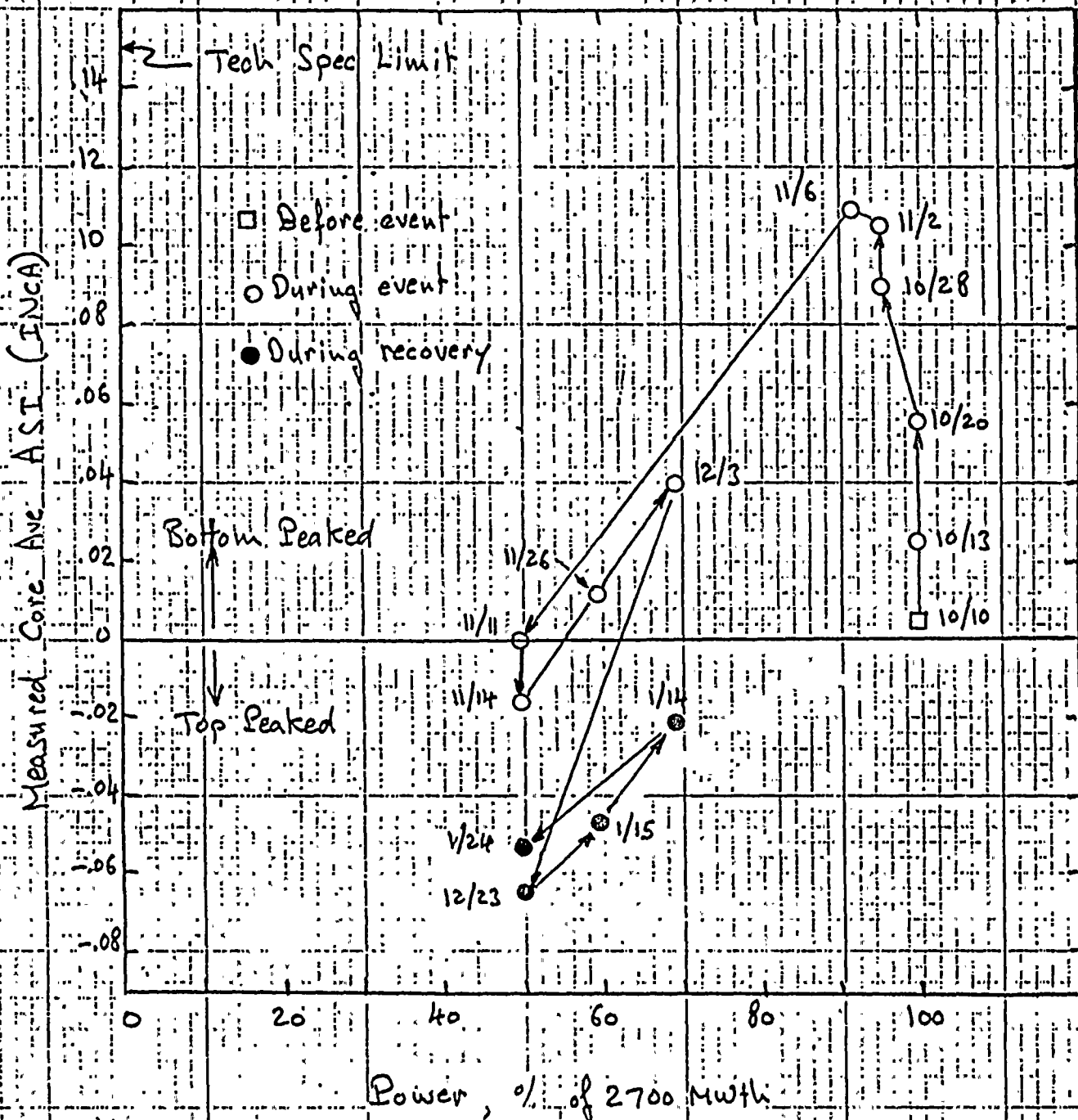


FIGURE III.2

Calvert - Cliffs I Cycle 4

Measured Axial Shape Index (ASI)
vs. Power and Time



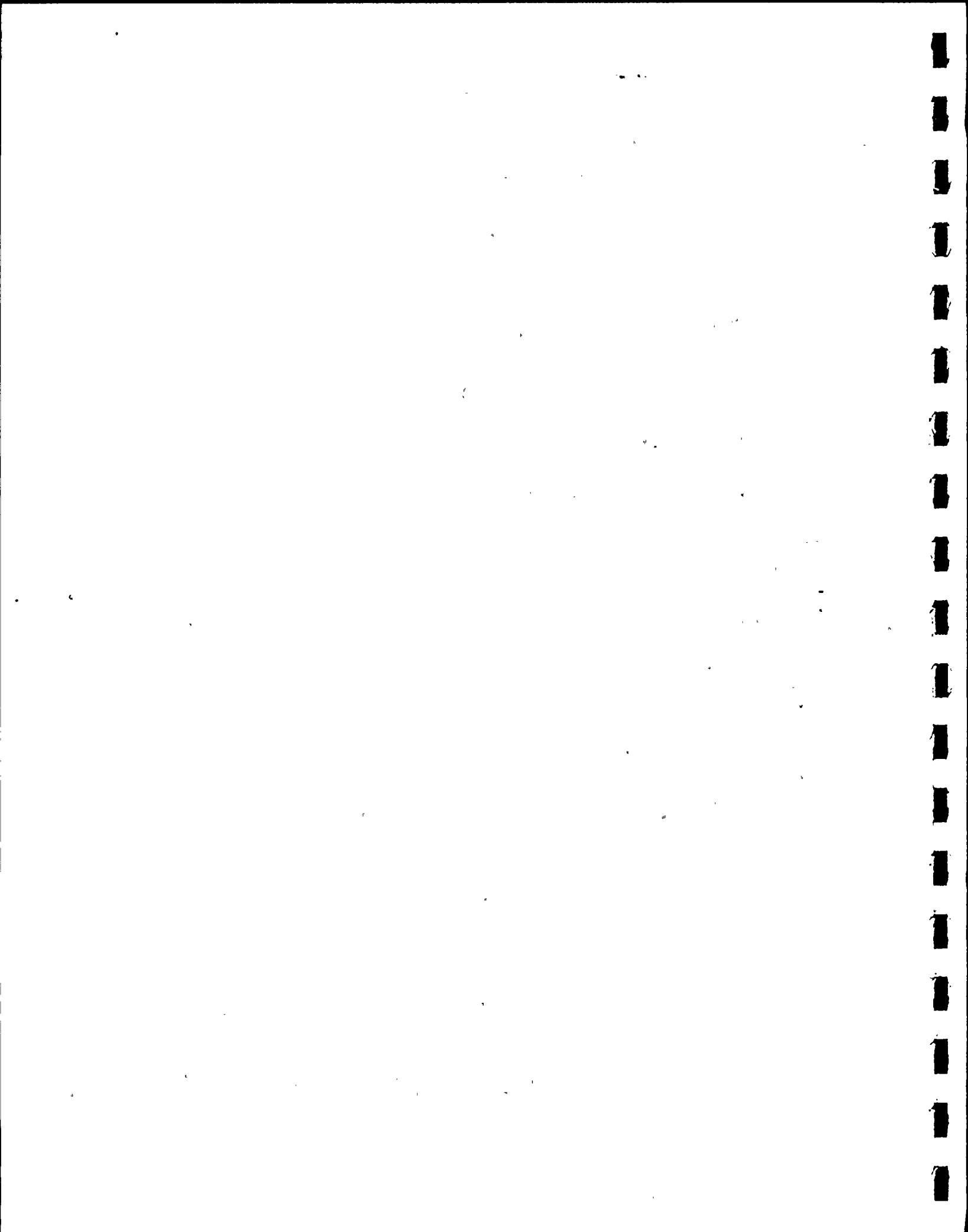
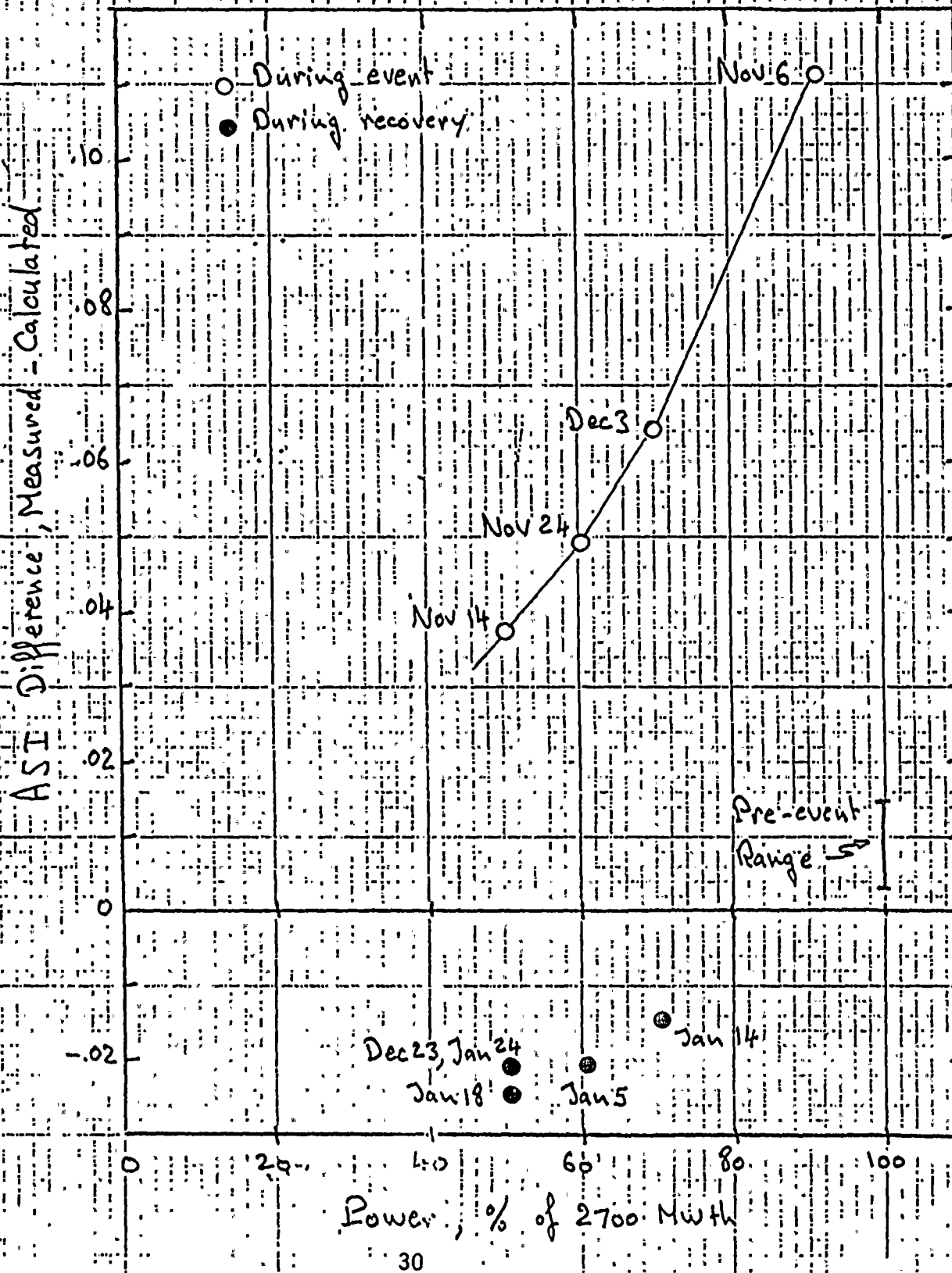


FIGURE III.3

Calvert Cliffs I Cycle 4

AST Difference vs. Power Level



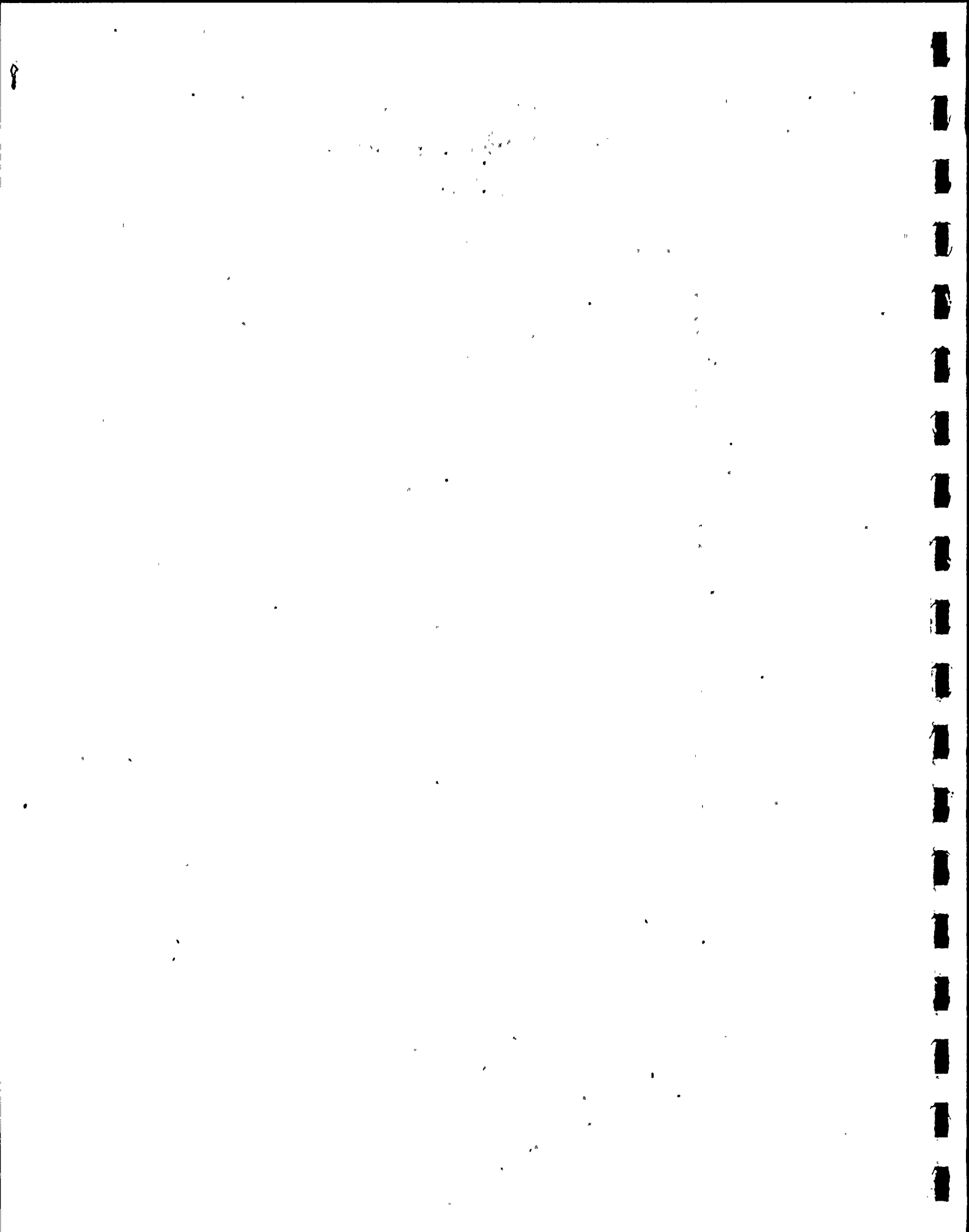
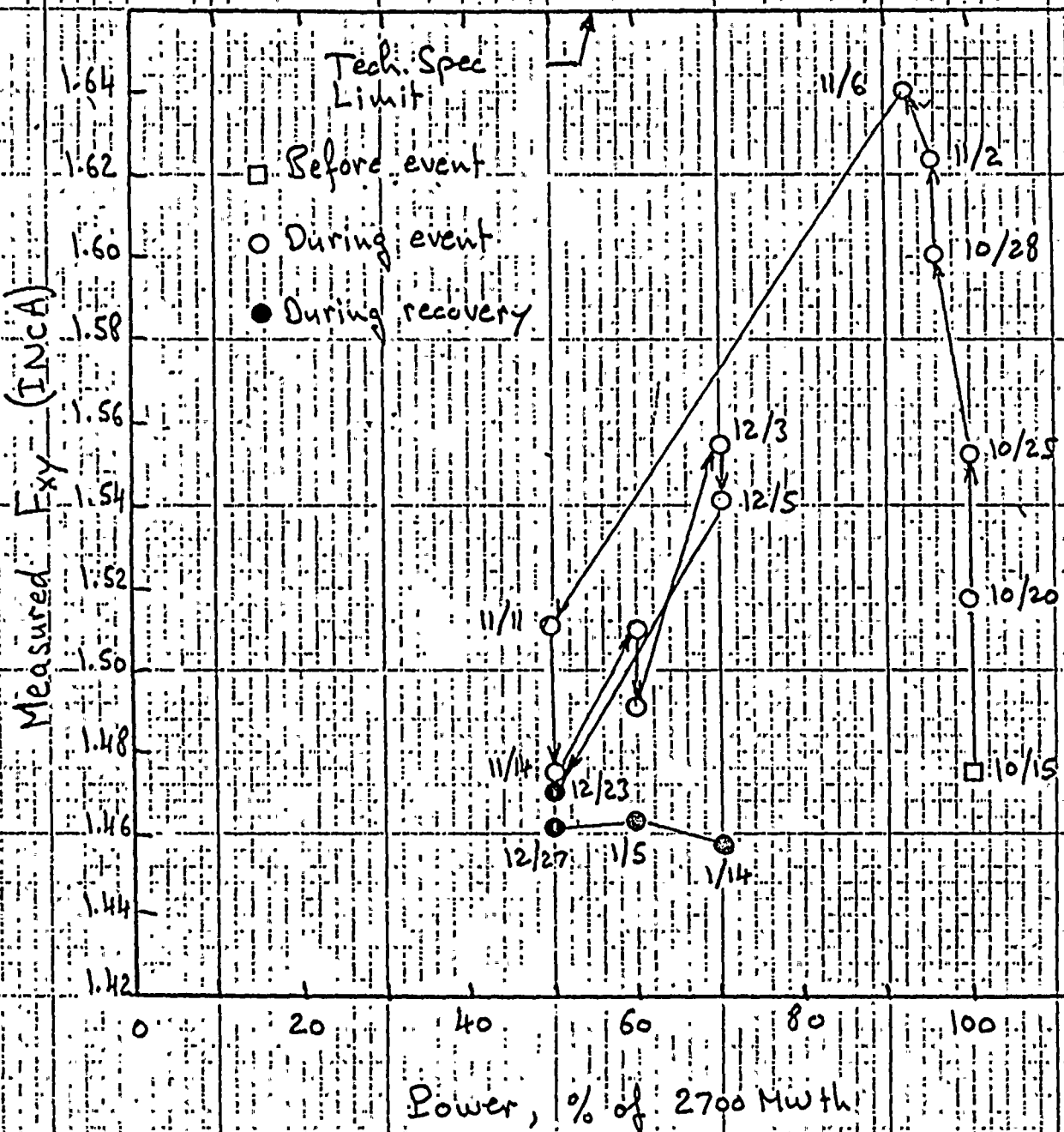


FIGURE III.4
Calvert Cliffs I Cycle 4
Measured Planar Peaking Factor F_{xy}
vs. Power and Time



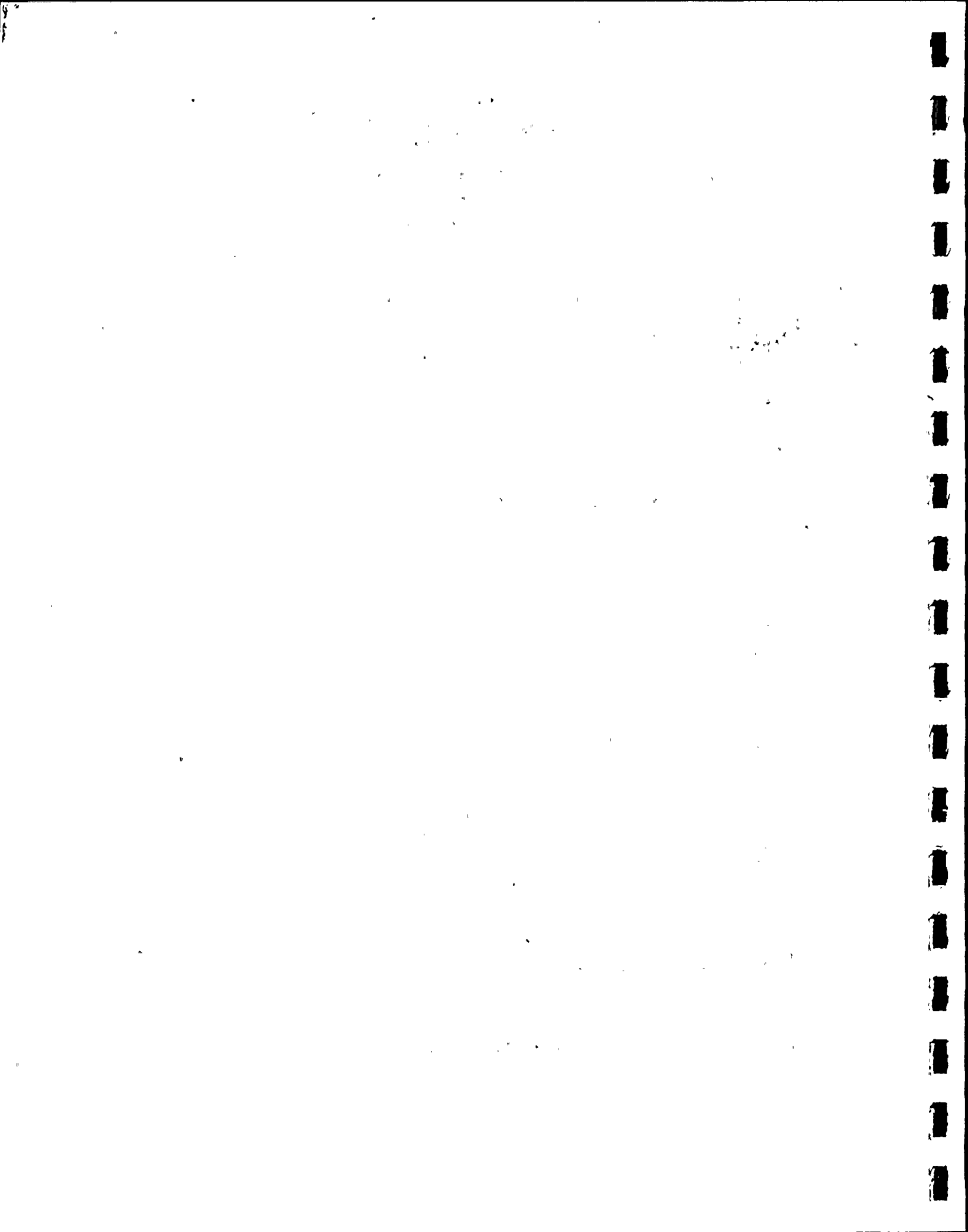


FIGURE III.5

Calvert - Cliffs I Cycle 4
Comparison of Measured and Predicted Radial
Power Distributions at 80% Elevation

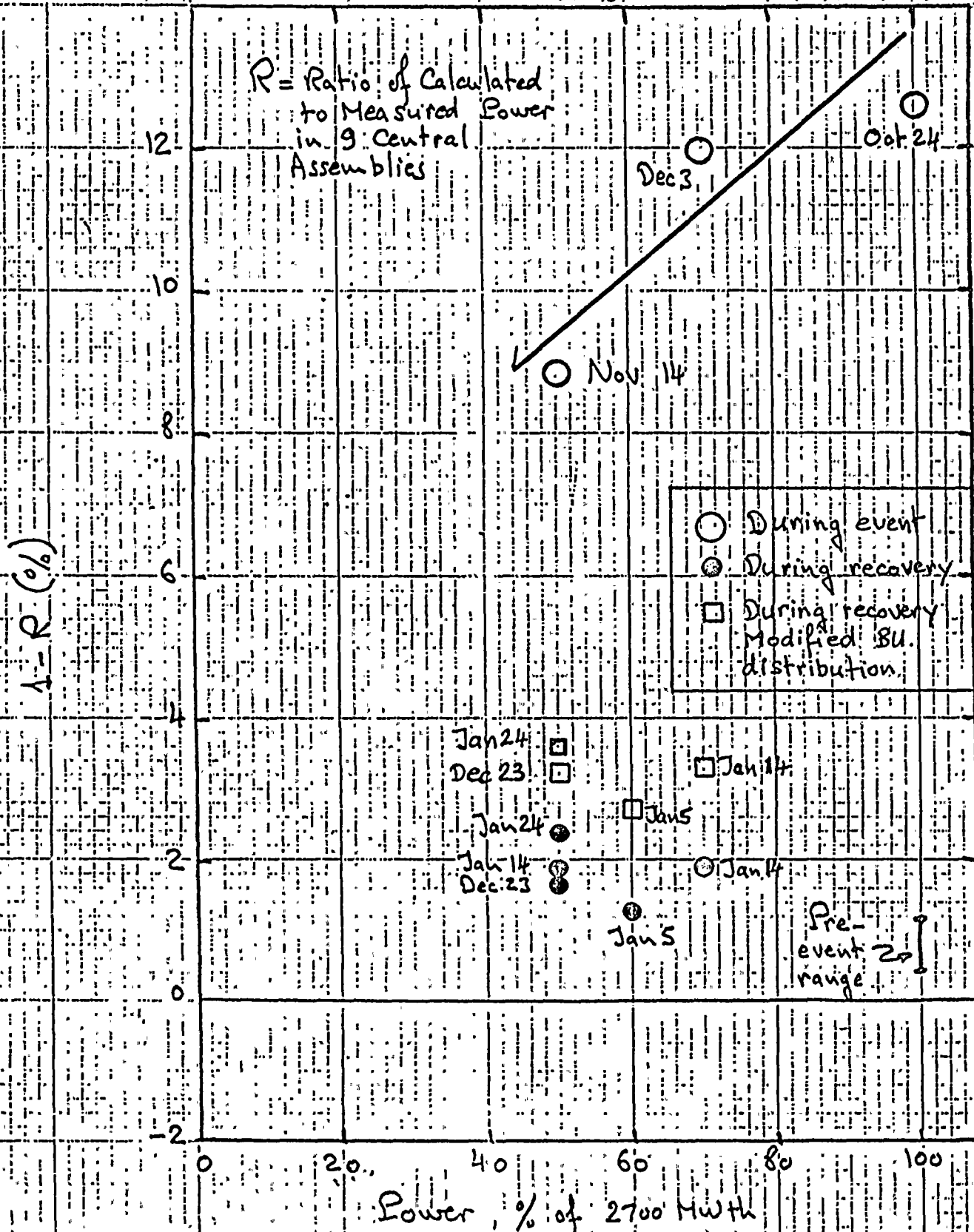


FIGURE III.6

Calvert Cliffs I Cycle 4
Comparison of Measured and Predicted Radial
Power Distributions at 20% Elevation

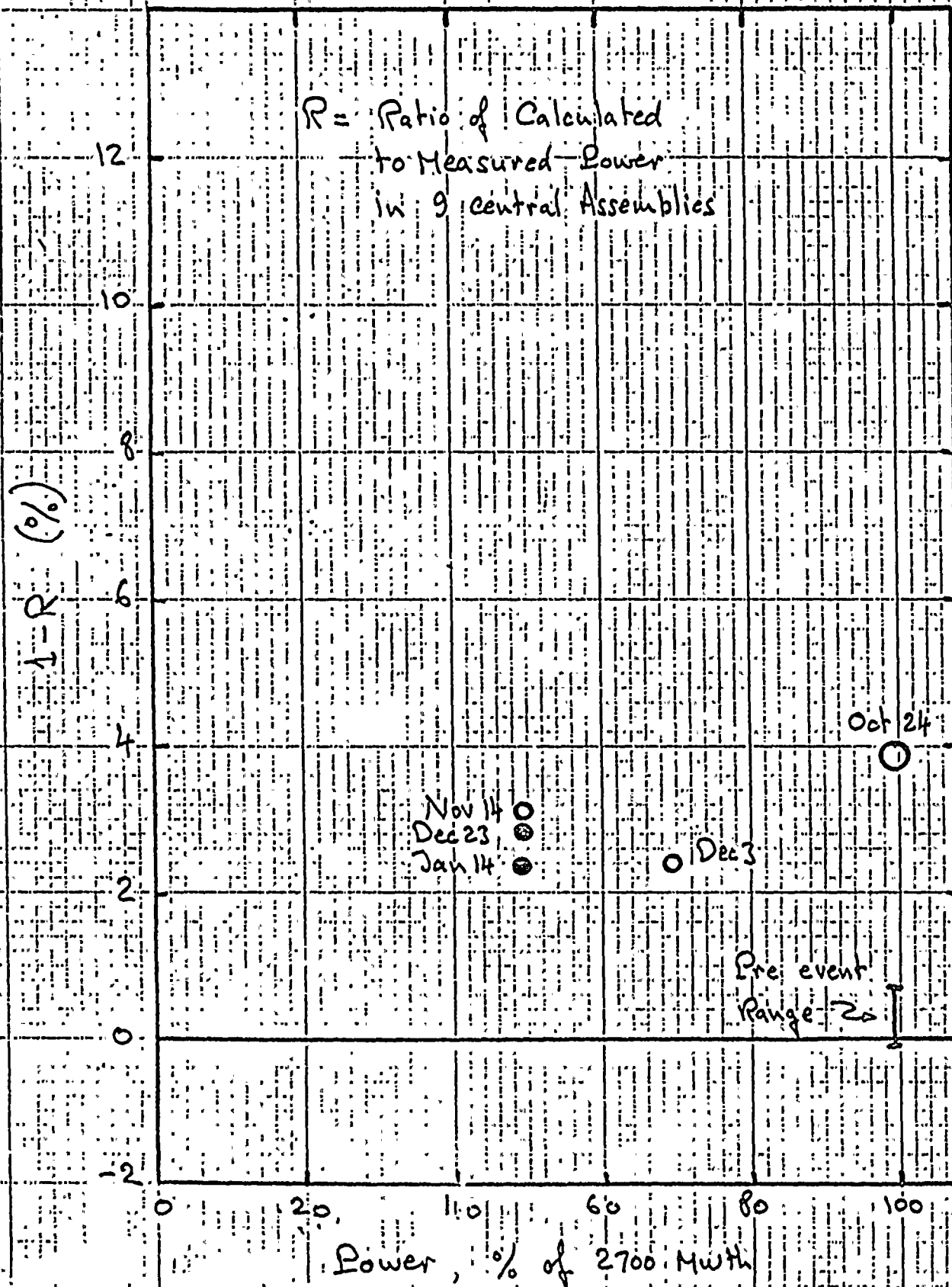
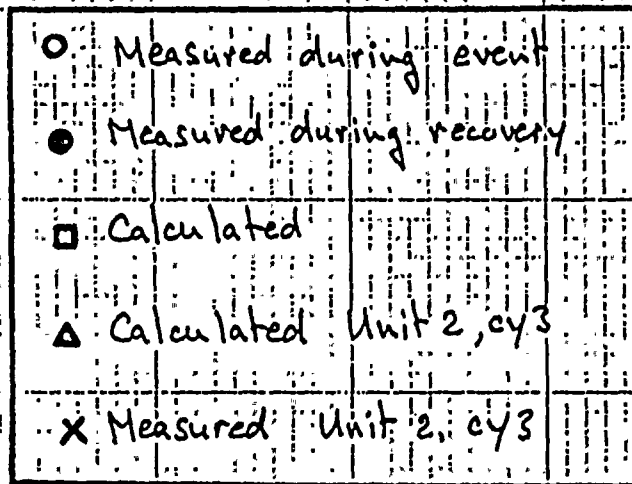


FIGURE III.7

Calvert Cliffs I Cycle 4 Power Coefficients* vs. Time

Power Coefficient $\times 10^{-4}$ Δg/% Power



* Adjusted when necessary to 50% power

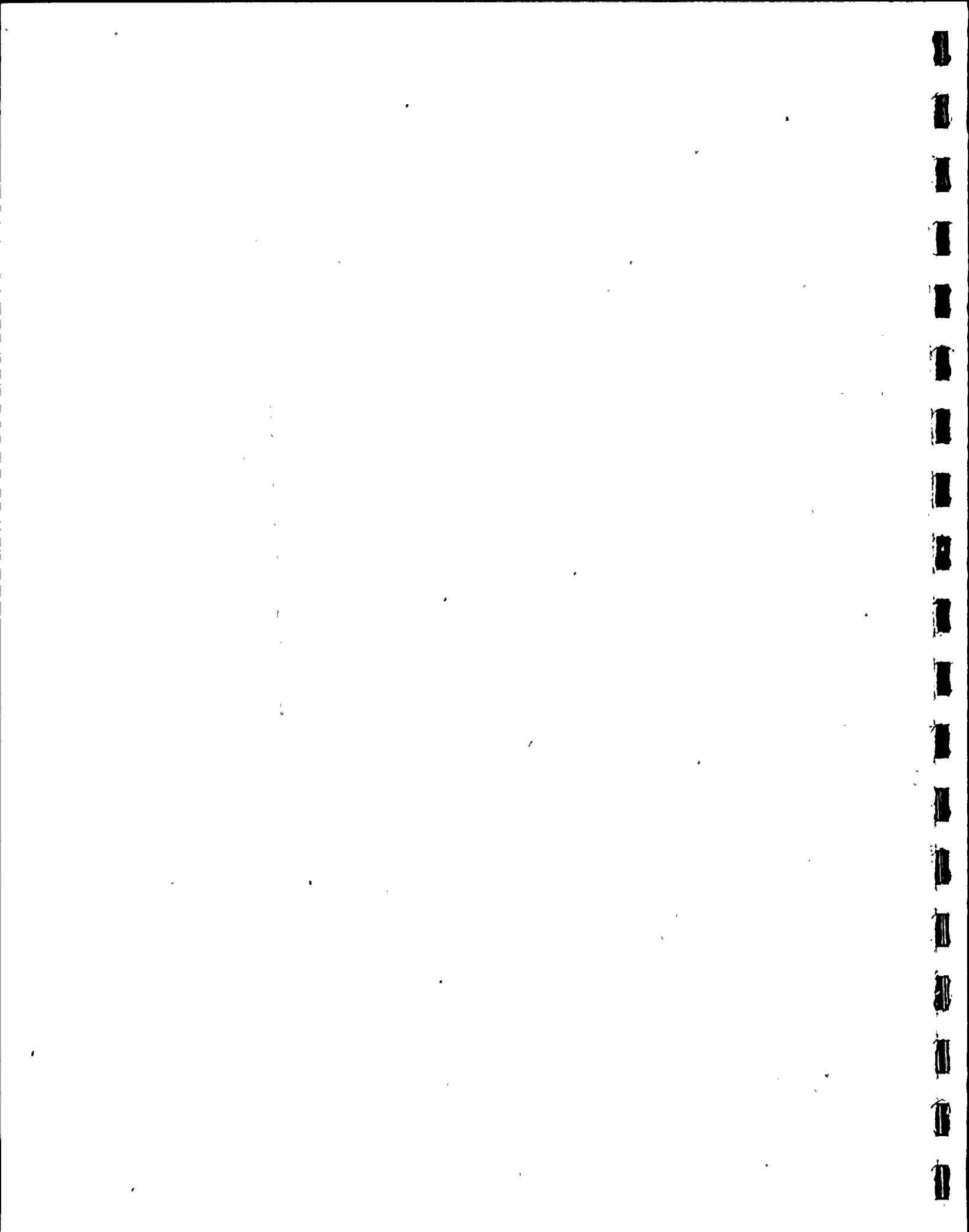


FIGURE III.8

Calvert Cliffs I Cycle 4

Calculated - Measured Power Coefficient
vs. Time

Power Coef. Difference, Calc. - Meas. ($\times 10^{-4} / \% P$)

- During event
- Recovery
- △ Unit 2

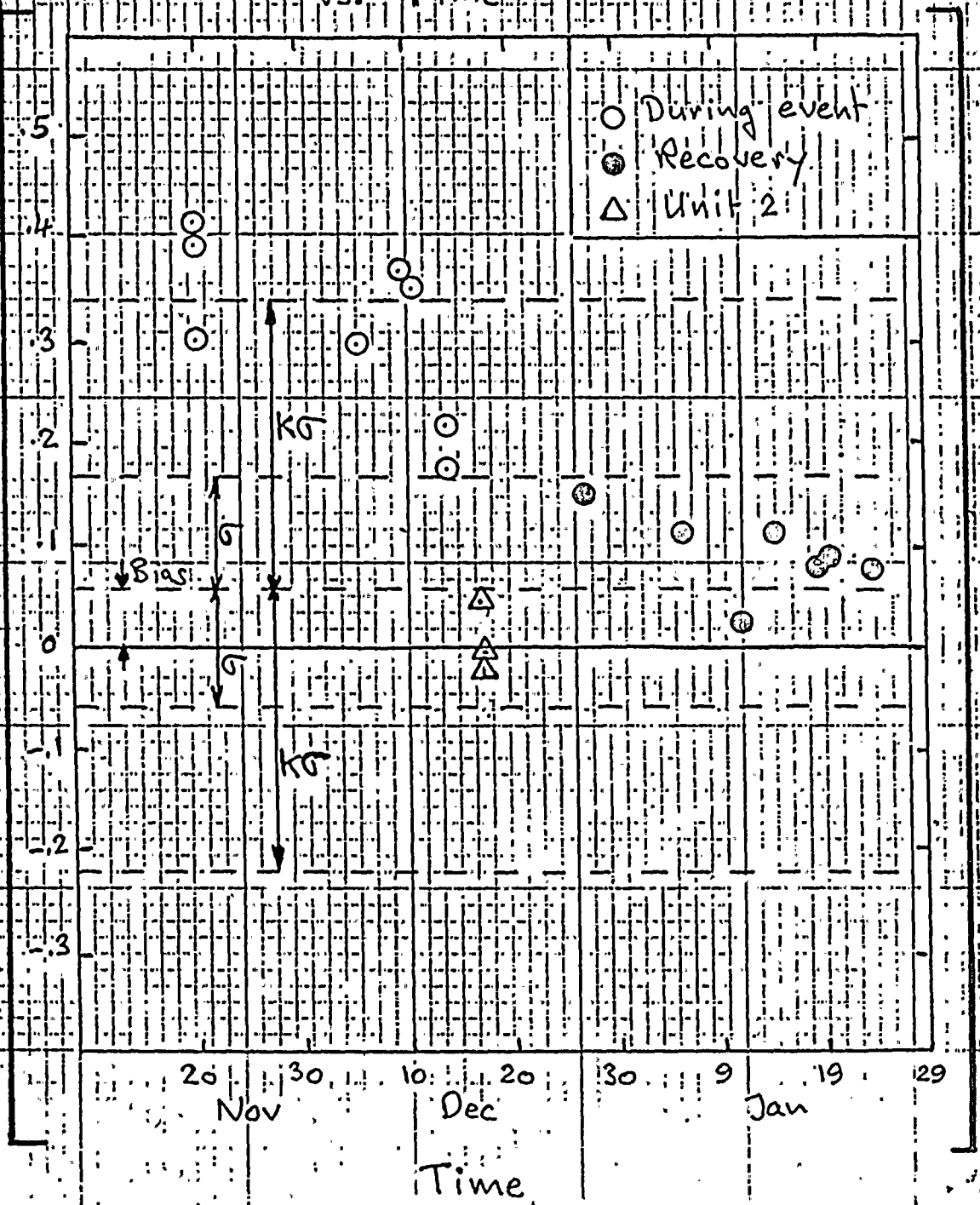
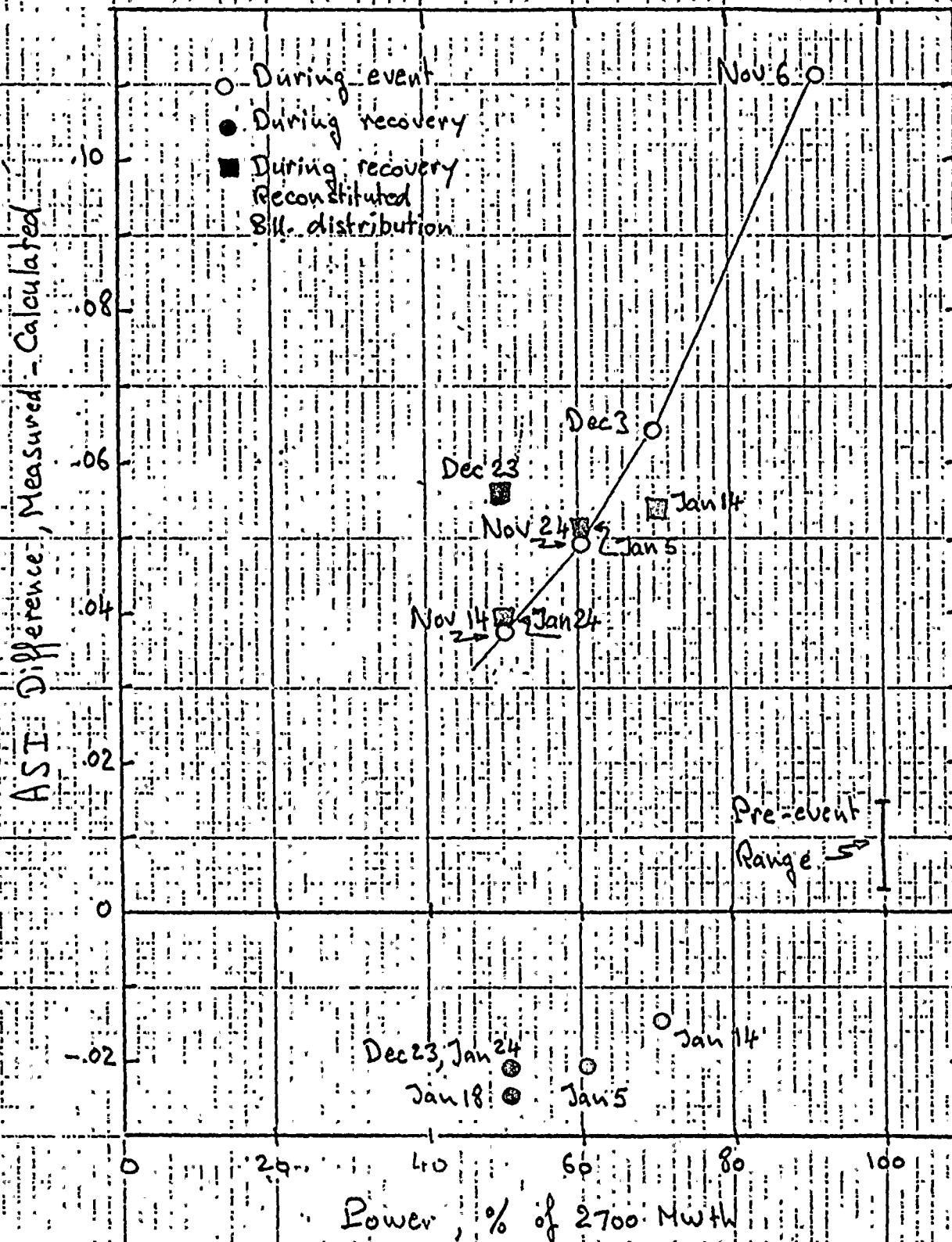


FIGURE III.9

Calvert Cliffs I Cycle 4

ASI Difference vs. Power Level



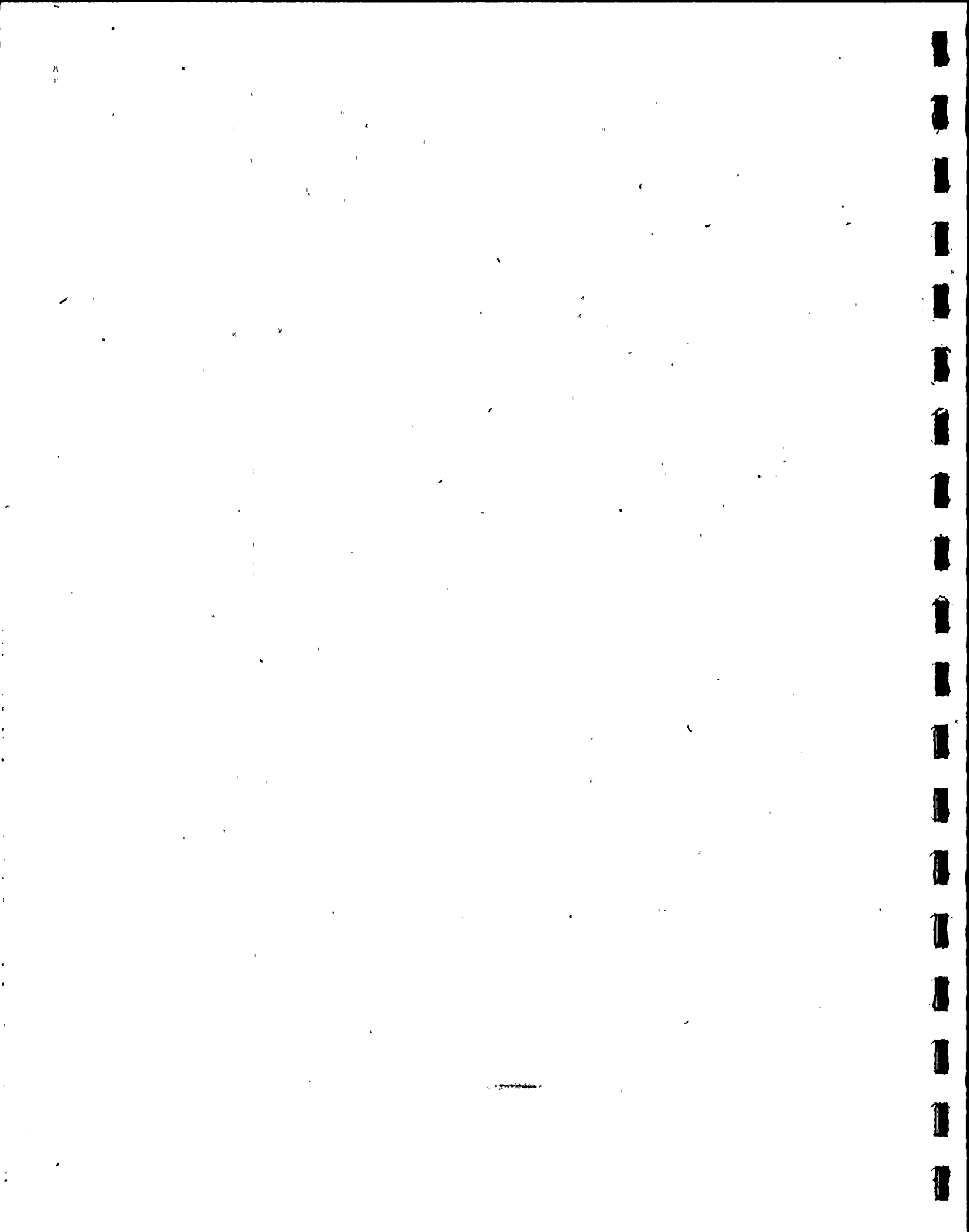
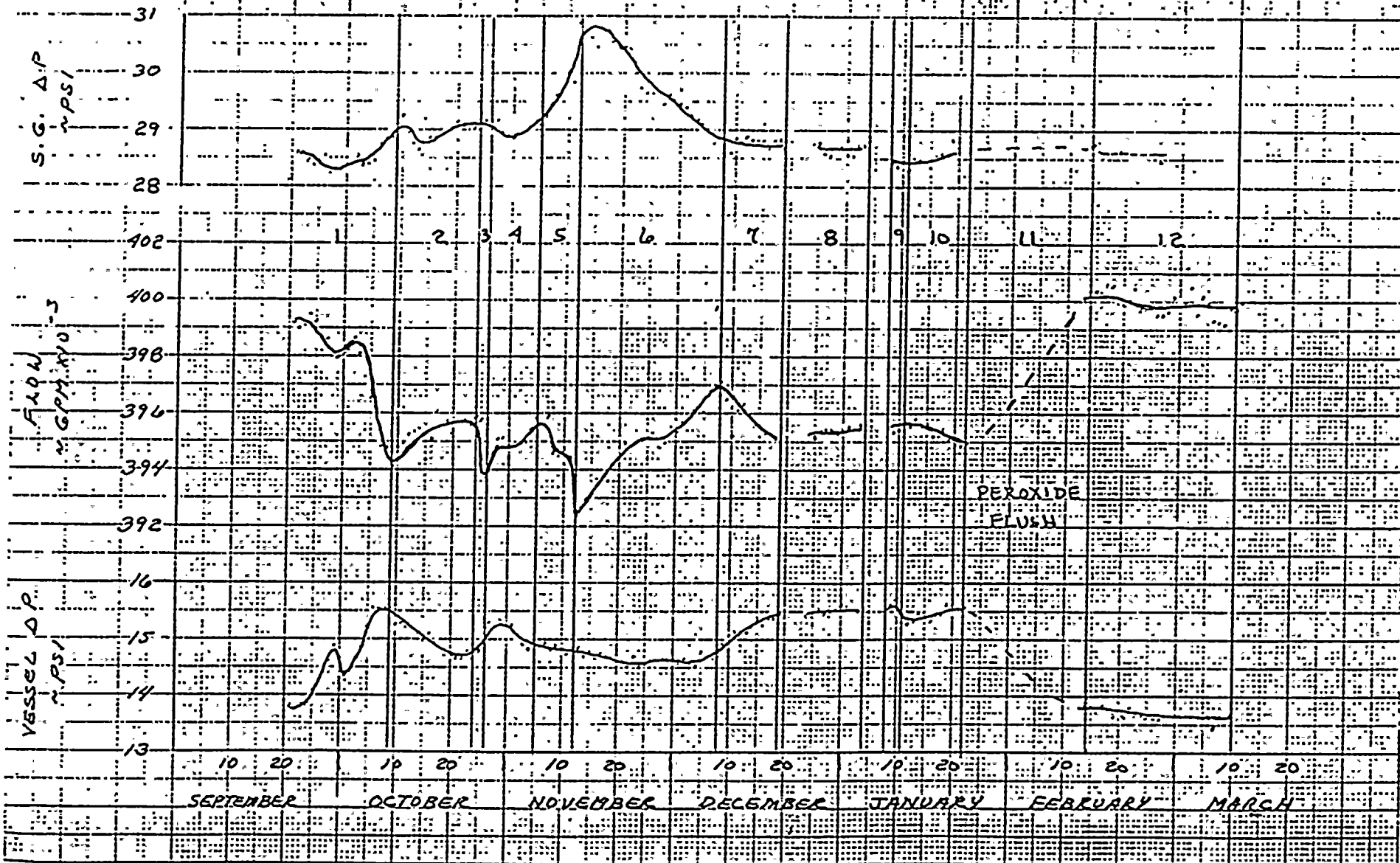


FIGURE III.10
CALVERT-CLIFFS I REACTOR COOLANT SYSTEM FLOW
AND ΔP TRENDS



- $\Delta X > 0.1$
- $0 \leq \Delta X \leq 0.1$
- ▲ $-0.1 < \Delta X < 0$

$$X = \left[\frac{T_{T/C} - \bar{T}_{IN}}{(\bar{T}_{OUT} - \bar{T}_{IN}) F_R} \right]$$

$$\Delta X = X_{10/30/79} - X_{8/31/79}$$

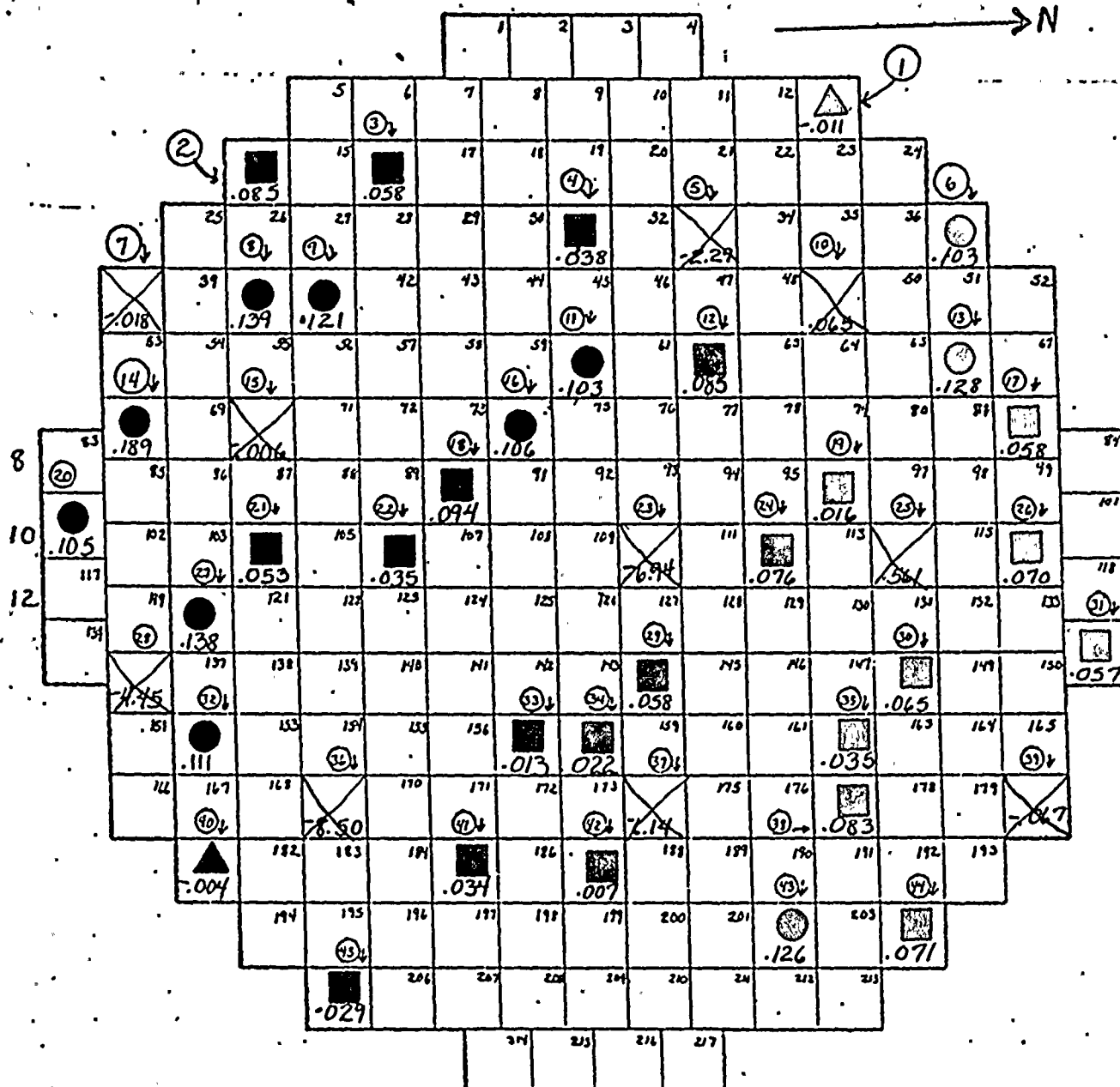


FIGURE III.11

THERMOCOUPLE READINGS COMPARED PRE-ANOMALY TO MID-ANOMALY



- $\Delta X > 0.1$
- $0 \leq \Delta X \leq 0.1$
- ▲ $-0.1 < \Delta X < 0$

$$X \equiv \frac{T_{T/C} - \bar{T}_{IN}}{(\bar{T}_{OUT} - \bar{T}_{IN}) F_R}$$

$$\Delta X = X_{10/20/79} - X_{9/14/79}$$

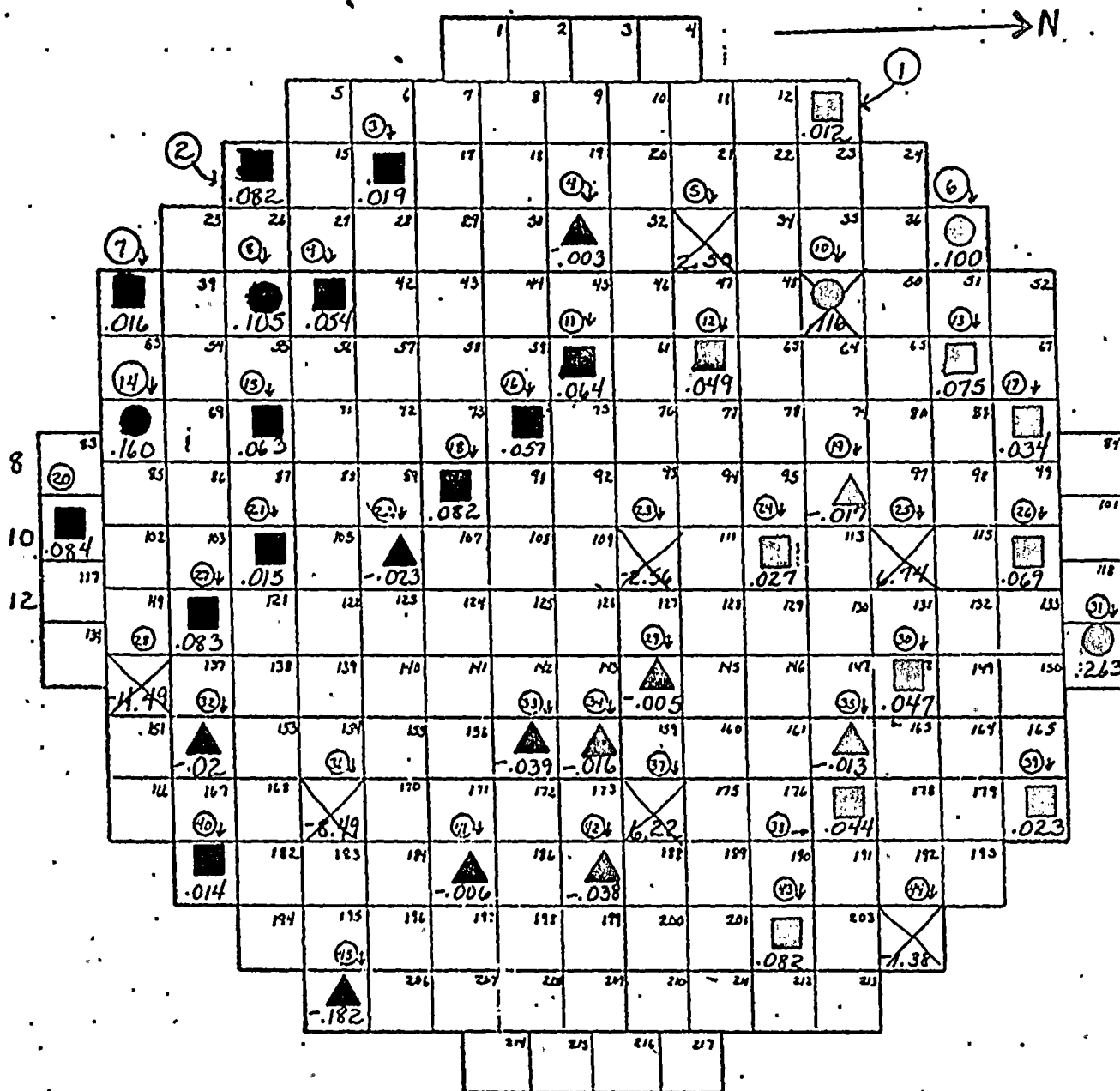
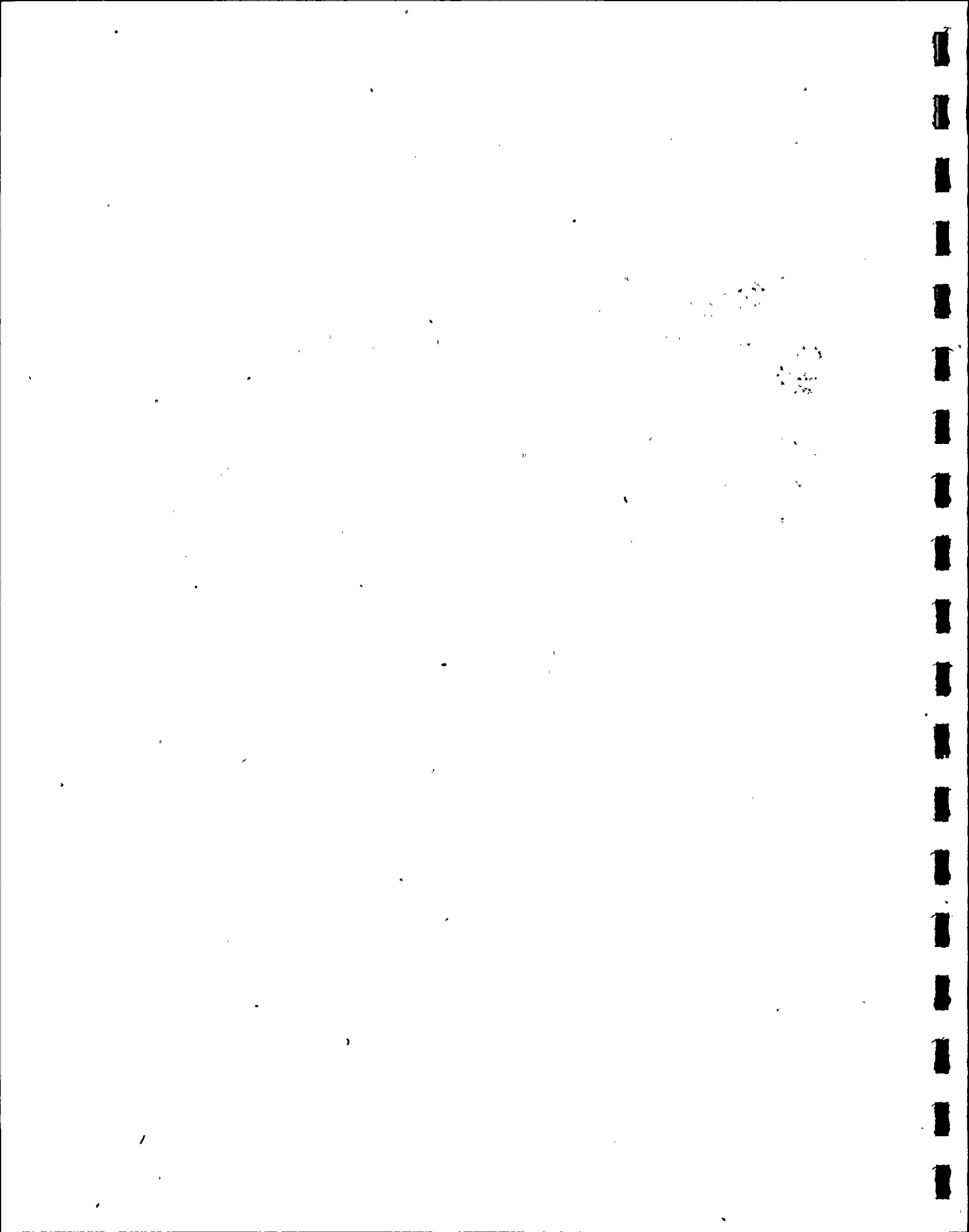


FIGURE III.12

THERMOCOUPLE READINGS COMPARED EARLY-ANOMALY TO MID-ANOMALY



IV. Chemistry Observations and Evaluations

A. Routine Water Chemistry Surveillance Program

The water chemistry program at Calvert Cliffs is outlined in a definitive set of procedures contained in Calvert Cliffs Instruction #406 (Attachment-(1a-d). Collectively, this set of chemistry and radiochemistry procedures forms the nucleus of a detailed, rigidly characterized system for the analysis of significant parameters to determine trends and identify abnormal conditions. The basis for the chemistry surveillance program at Calvert Cliffs is formed from the Combustion Engineering (CE) Power System Nuclear Steam Supply System Chemistry Manual (CENPD - 28) (Reference 1). The analytical methodologies, sampling locations, sampling frequencies and parameter specifications recommended in the CE Chemistry Manual have been strictly incorporated into the site specific Calvert Cliffs chemistry program. Insofar as the Calvert Cliffs Unit 1 Power Distribution Episode is concerned, the chemistry control of the following systems need be evaluated:

1. Reactor Coolant System (RCS)
2. Chemical and Volume Control System (CVCS)
3. Makeup Demineralized Water System (RC M/U)



1. Reactor Coolant System

A detailed discussion of the Reactor Coolant System chemistry monitoring program is contained in Chemistry Procedure 1-202 (Reference 2). Table 1 of RCP 1-202 (Attachment 2a-b), characterizes the procedures/specifications/frequencies associated with significant parameters in the RCS. This is a site specific procedure which incorporates the recommendations of CENPD-28 as regards RCS chemistry. Specification Sheet # 3-3 (Attachments 3a, b, c and d), outlines the CE recommended sampling location, frequencies, specifications and corrective actions for the analysis specified. As regards the power distribution episode the following RCS chemistry parameters are of significance: (a) pH, (b) conductivity, (c) lithium, (d) suspended solids, (e) hydrogen, (f) iodine 131/133, (g) iodine ratio, (h) ammonia. Nominal RCS water chemistry is illustrated in Figures 1A - H for the period of time 07/01/80 to 07/31/80. It is readily apparent from an examination of the figures that the water chemistry parameters were controlled to values well within both the CE and site specific limits.

Table IV.A.1 summarizes the nominal observed chemistry values obtained from examination of the figures together with both the CE recommended and site specific guidelines.

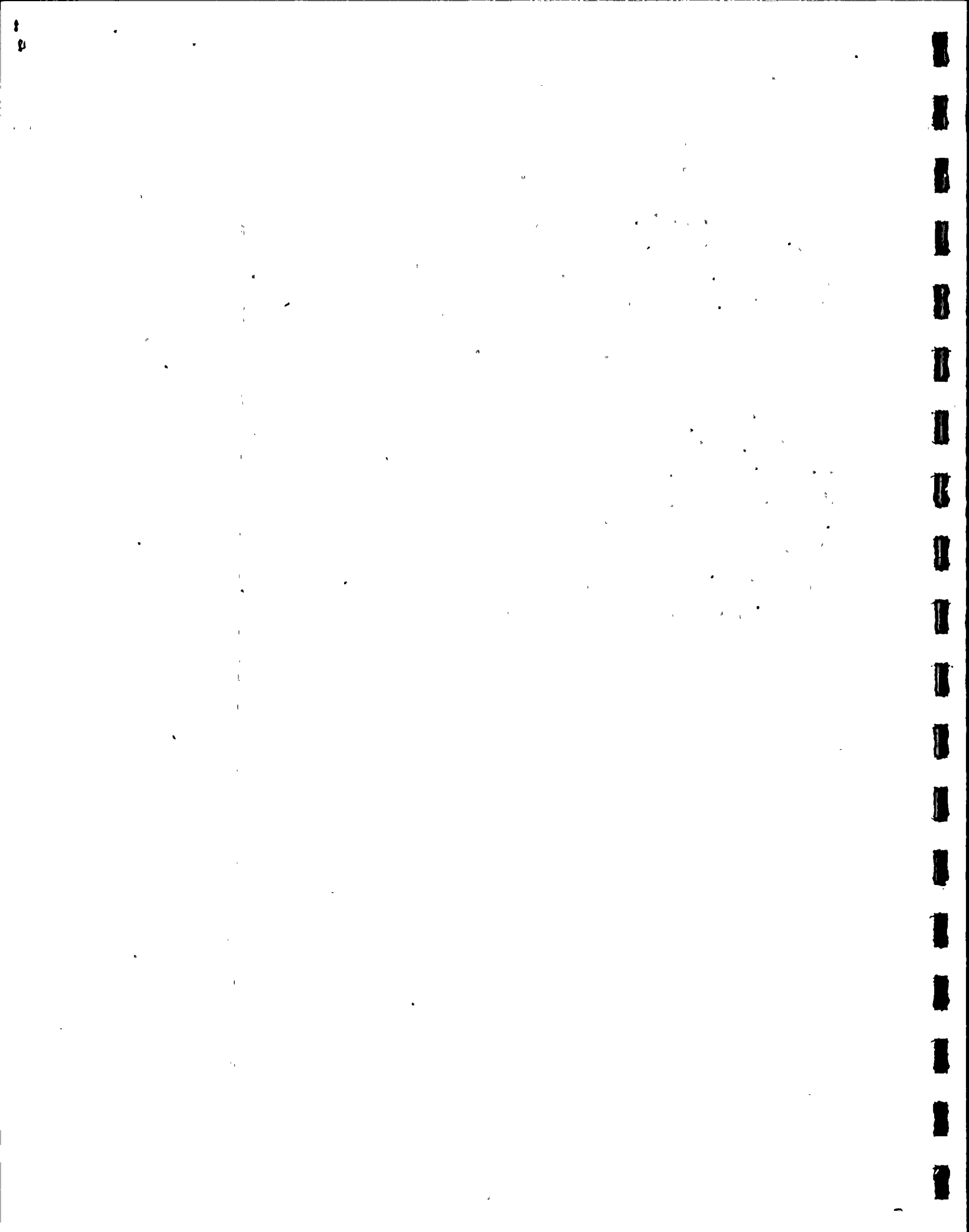


TABLE IV.A.1

Parameters (Units)	Nominal Observed Value	CE Recommended	Site Specific
(a) pH (Standard) Unit at 25 C°	5.0 to 7.0	4.5 to 10.2	4.5 to 10.2
(b) Specific Conductivity (μ mho/cm)	0.0 to 20.0	Consistent with concentration of additives	Consistent
(c) Lithium (ppm)	0.0 to 1.0	0.2 to 1.0	1 ppm maximum
(d) Suspended Solids s/s (ppb)	0.0 to 250	500 or 2000 (4 hrs.)	500 maximum
*(e) Hydrogen (cc/kg)	10 to 60	10 to 50	10 to 50
(f) Oxygen (ppb)	<10	<100	<100
(g) Activity I ¹³¹ /I ¹³³	N/A	Not Specified	Not Specified
(h) Ammonia (ppb)	<25	<500	Not Specified

*It should be noted that the CE recommended analysis method for RCS hydrogen concentration is by means of volume control tank calculations.



FIGURE 1A

SECTION IV. A

PH @ 25°C
07/01 - 07-31/1979

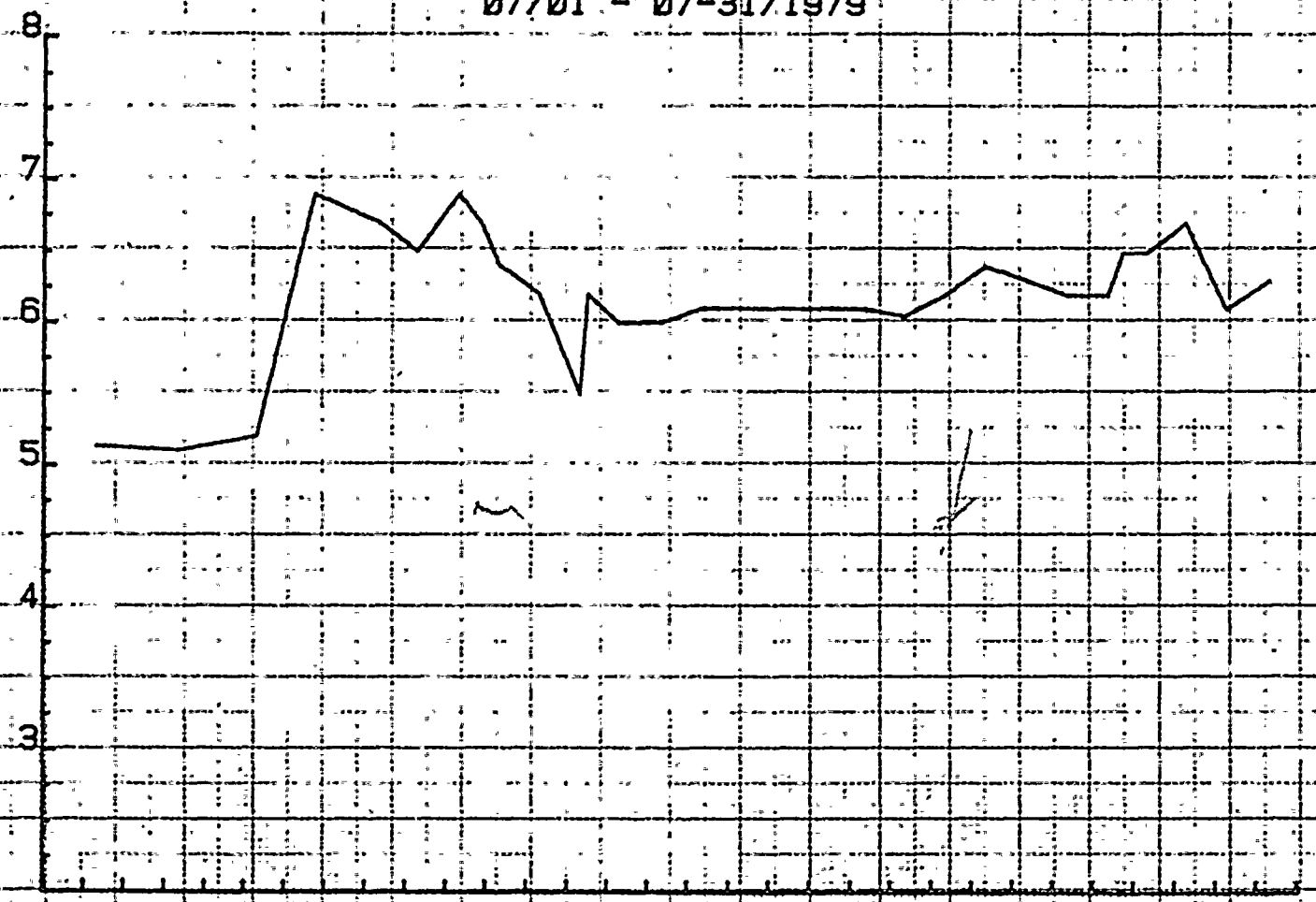




FIGURE 1B

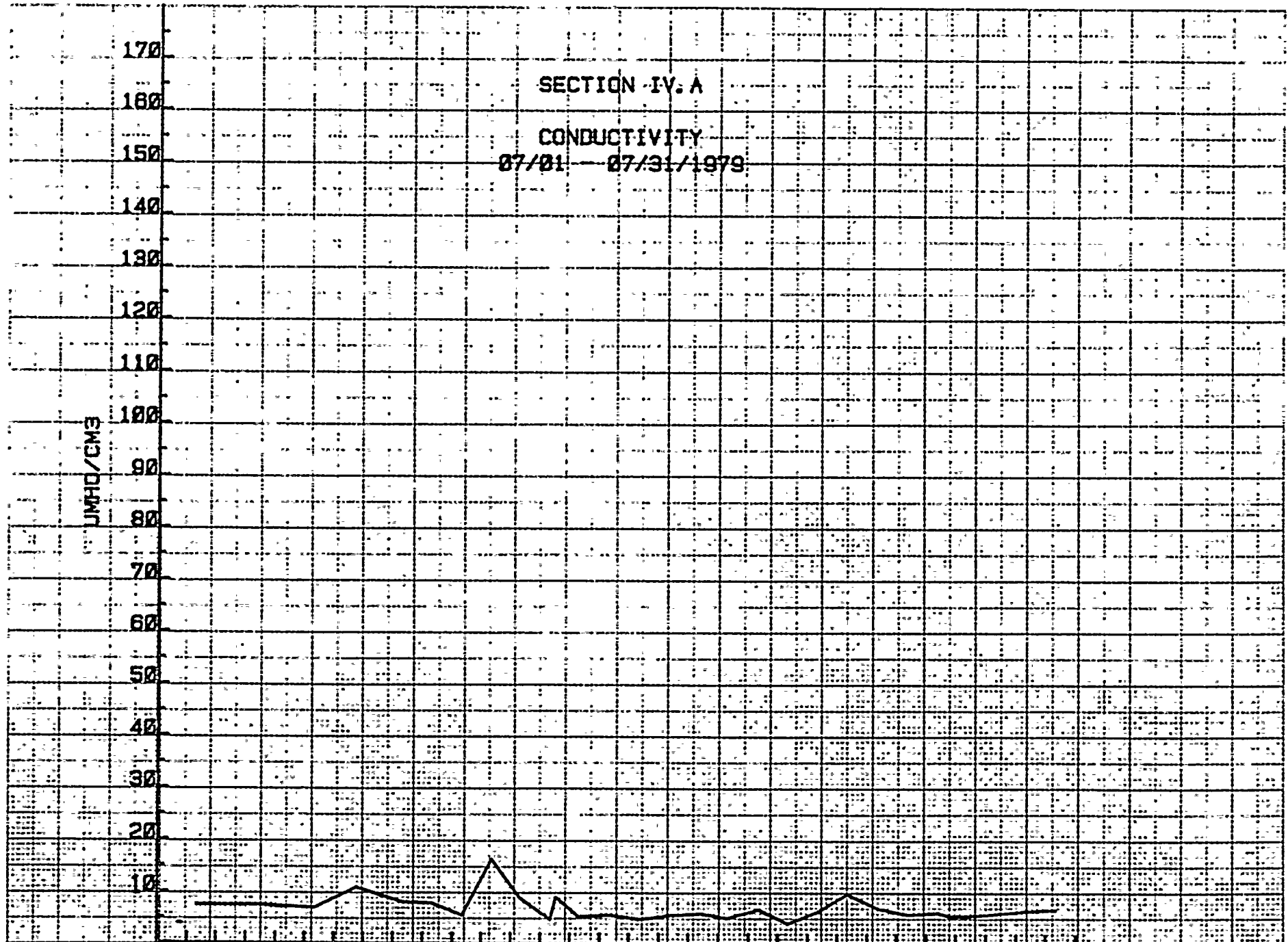
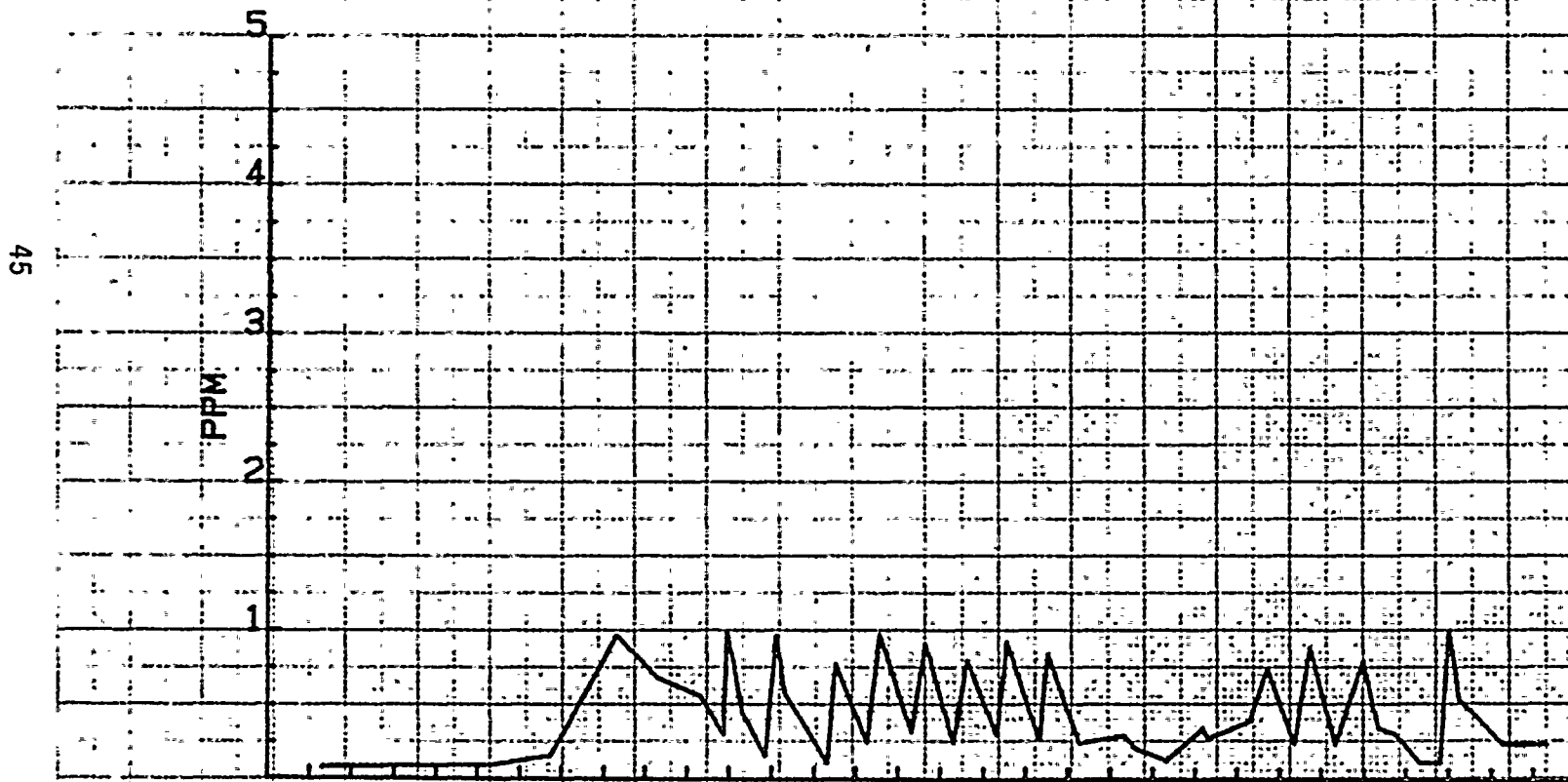


FIGURE 1C

SECTION IV.A
LITHIUM
07/01 - 07-31/1979



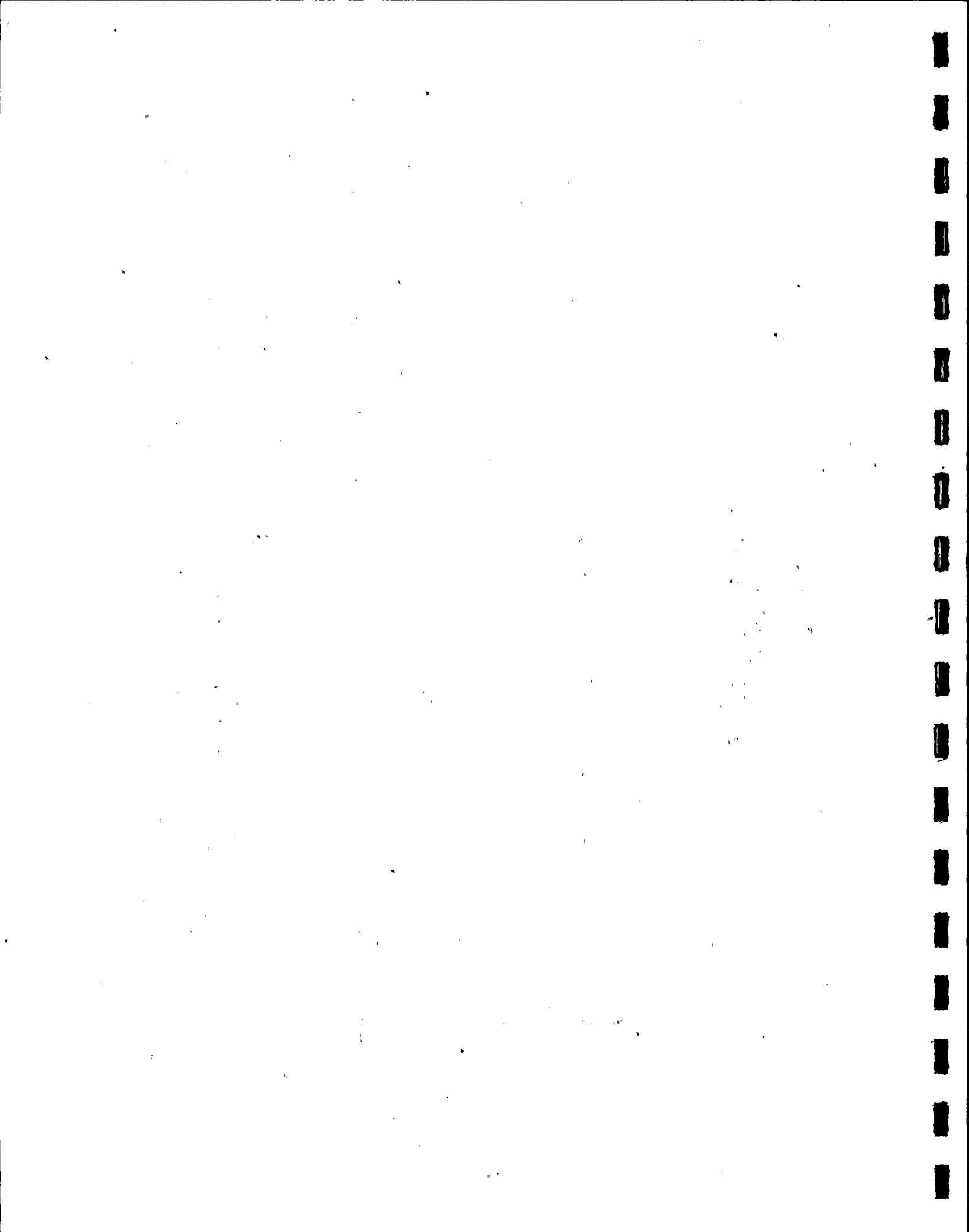
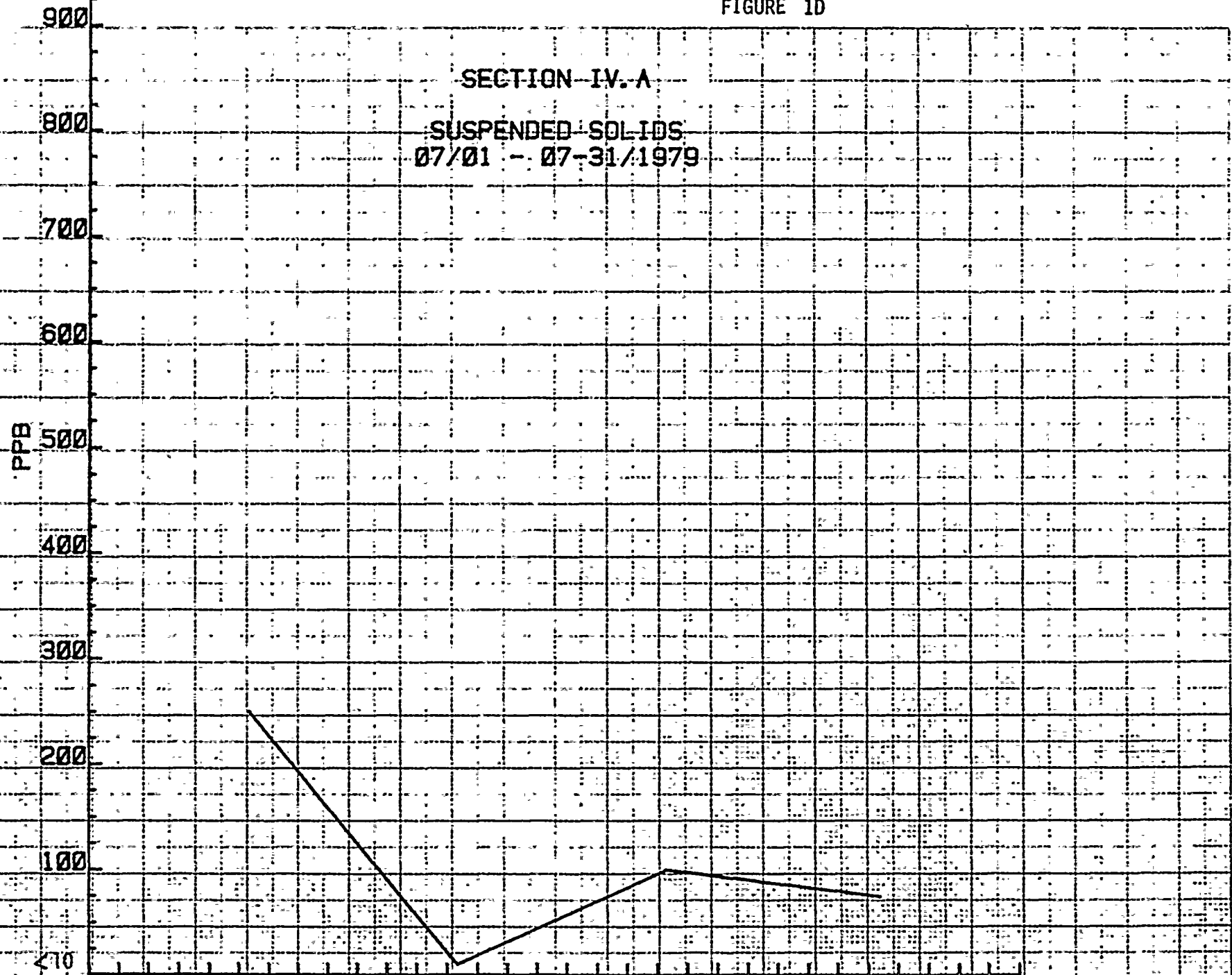


FIGURE 1D



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FIGURE 1E

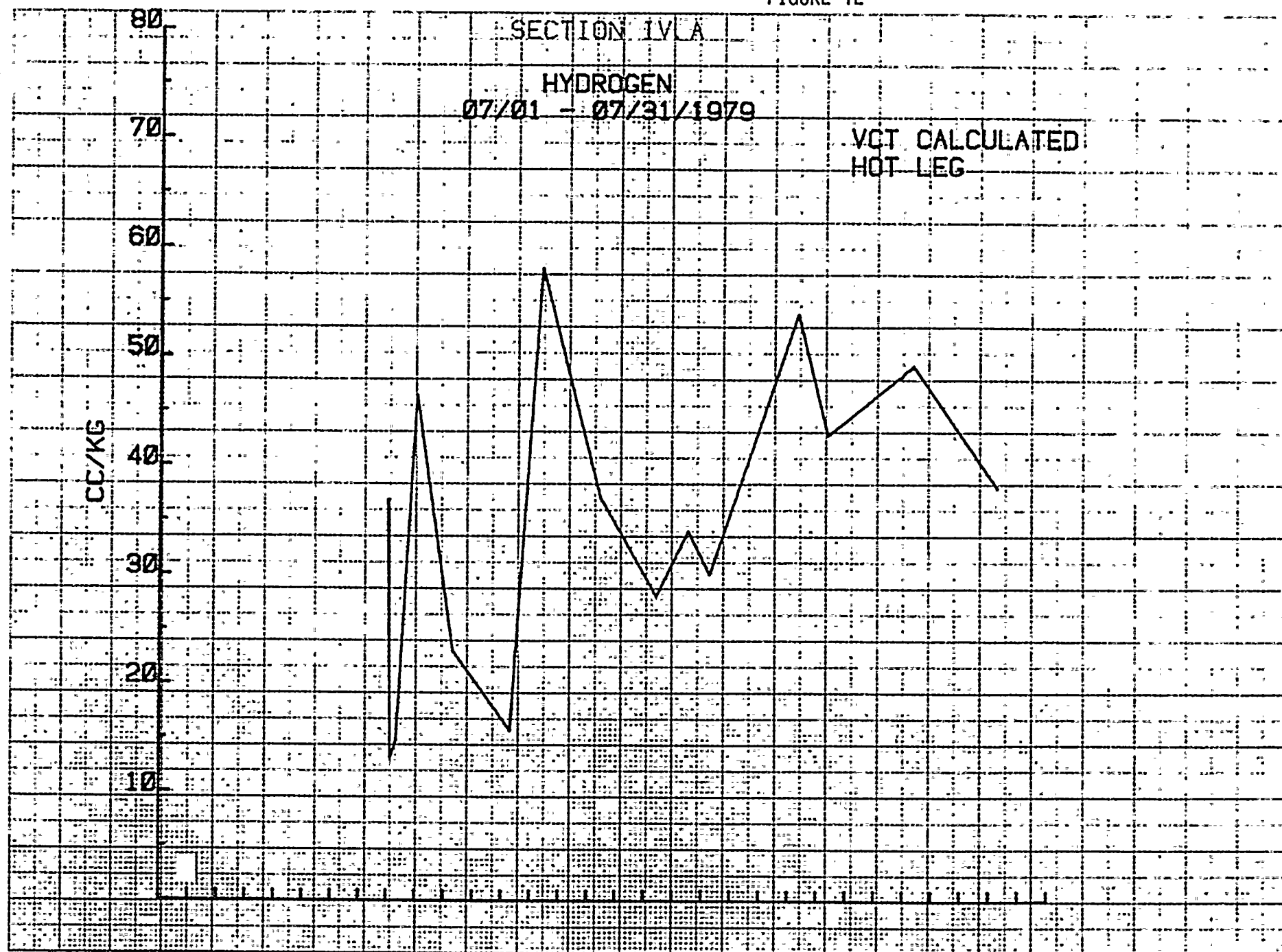


FIGURE 1F

SECTION IV.A

IODINE
07/01 - 07/31/1979

DO/DO

IODINE 133

IODINE 131

REFUELING OUTAGE

48

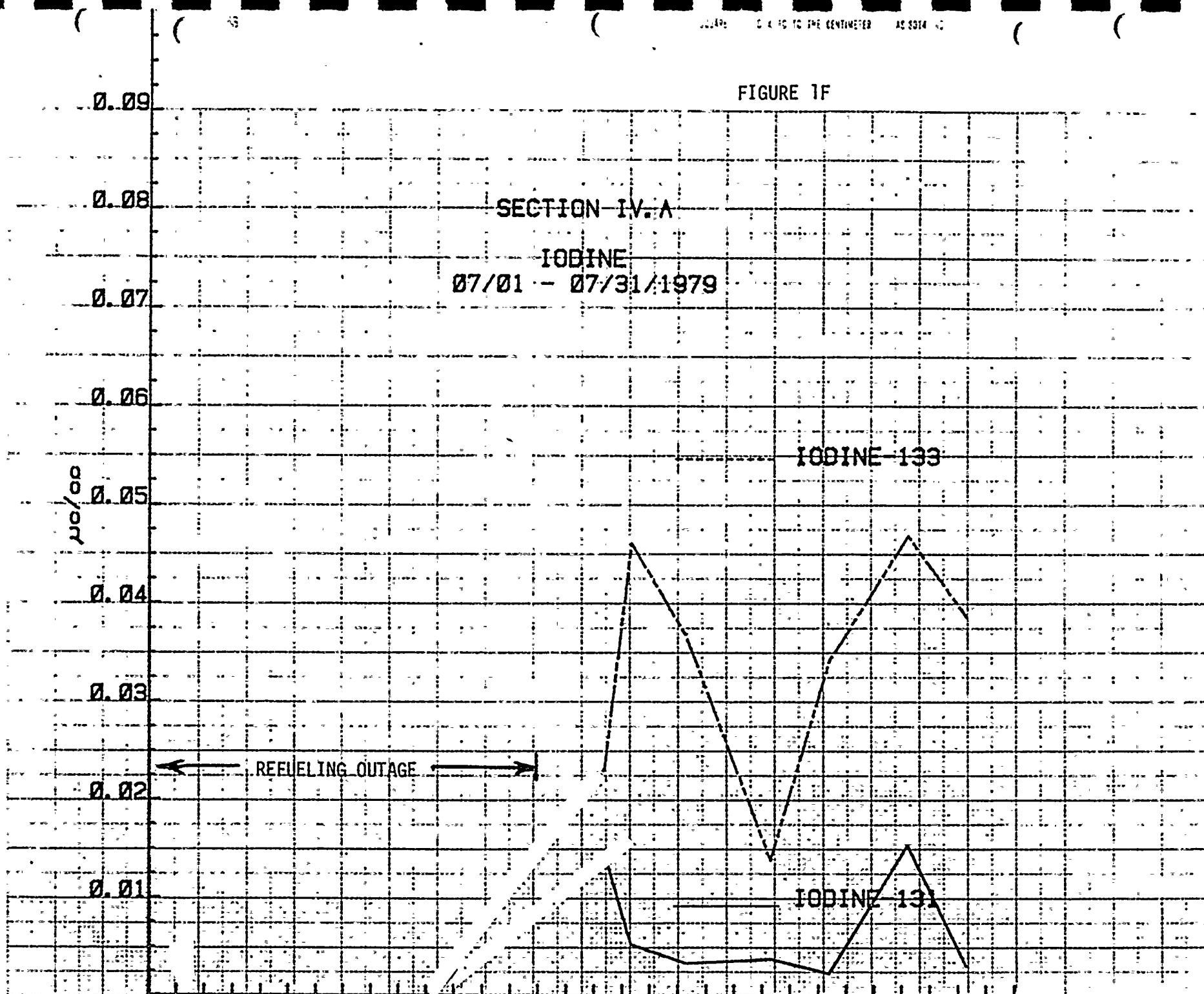


FIGURE 1G

SECTION IV.A
IODINE RATIO
07/01 - 07/31/1979

0.90

0.80

0.70

0.60

0.50

0.40

0.30

0.20

0.10

REFUELING OUTAGE

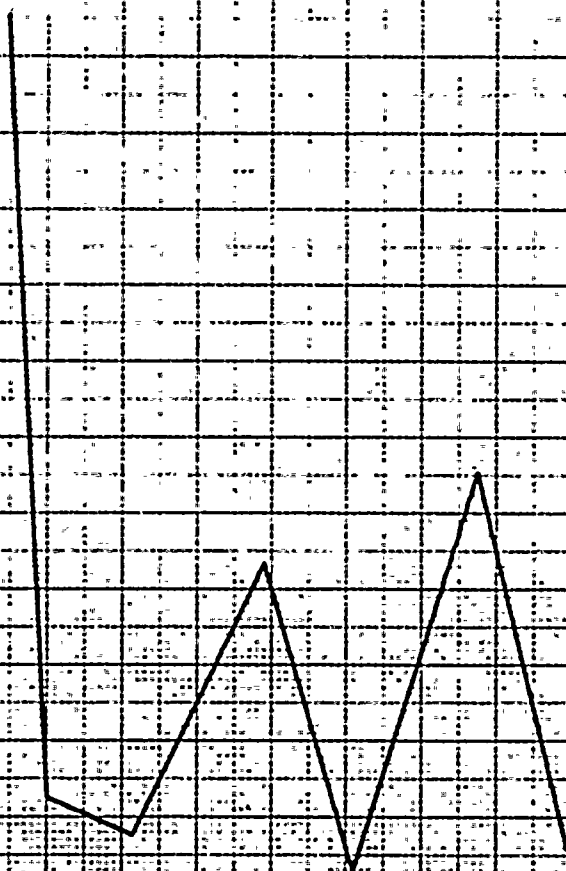


FIGURE 1H

PPM

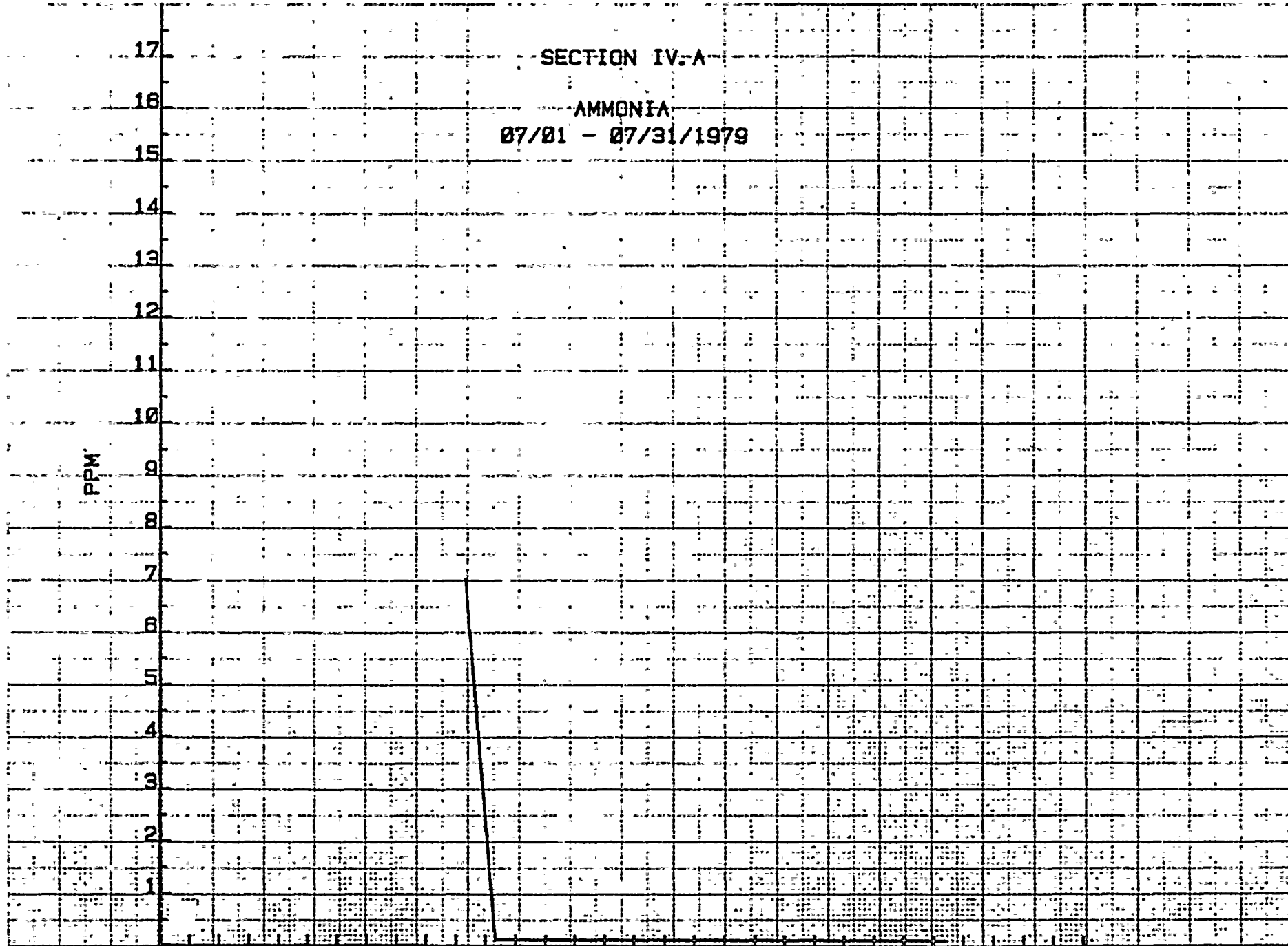
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3
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SECTION IV-A

AMMONIA

07/01 - 07/31/1979

50



2. Chemical and Volume Control System

A detailed discussion of the CVCS chemistry monitoring program is contained in Chemistry Procedure 1-215 (Attachment 4) which characterizes the procedures/specifications and frequencies associated with parameters of a critical nature in the CVCS. This is a site specific procedure which incorporates the recommendations of CENPD-28 (Reference 1). Insofar as the power distribution episode is concerned the parameter of significance is the volume control tank (VCT) hydrogen over-pressure. The recommended hydrogen over pressure of 9-45 psia corresponds to VCT calculated hydrogen concentrations of 10-50 cc/kg. This is dependent upon establishing nominal values for vapor phase hydrogen concentrations. VCT hydrogen concentrations are illustrated in Attachment 1E. Inspection of the data demonstrates that VCT over pressure (calculated RCS hydrogen concentration) was within specification during routine operations.

3. Makeup Demineralized Water System

A comprehensive explanation of the reactor coolant makeup water system (RC M/U) chemistry monitoring program is located in chemistry Procedure 1-201 (Reference 4). Table 1 of RCP1-201 (Attachment 5) describes the procedures/specifications and frequencies associated with the reactor coolant system. This is a site specific procedure which incorporates the recommendations of CENPD-28 (Reference 1). The recommended chemistry guidelines of CENPD-28 as regards RC M/U are illustrated in table form as specification Sheet 2-1 (Attachment 6a-b). Examination of the operational chemistry data logsheets (Reference 5) verified that routine chemistry values were within the guidelines of both the site specific and CE specifications. Table IV.A.2 illustrates the nominal observed values obtained for significant parameters together with the recommended specifications.

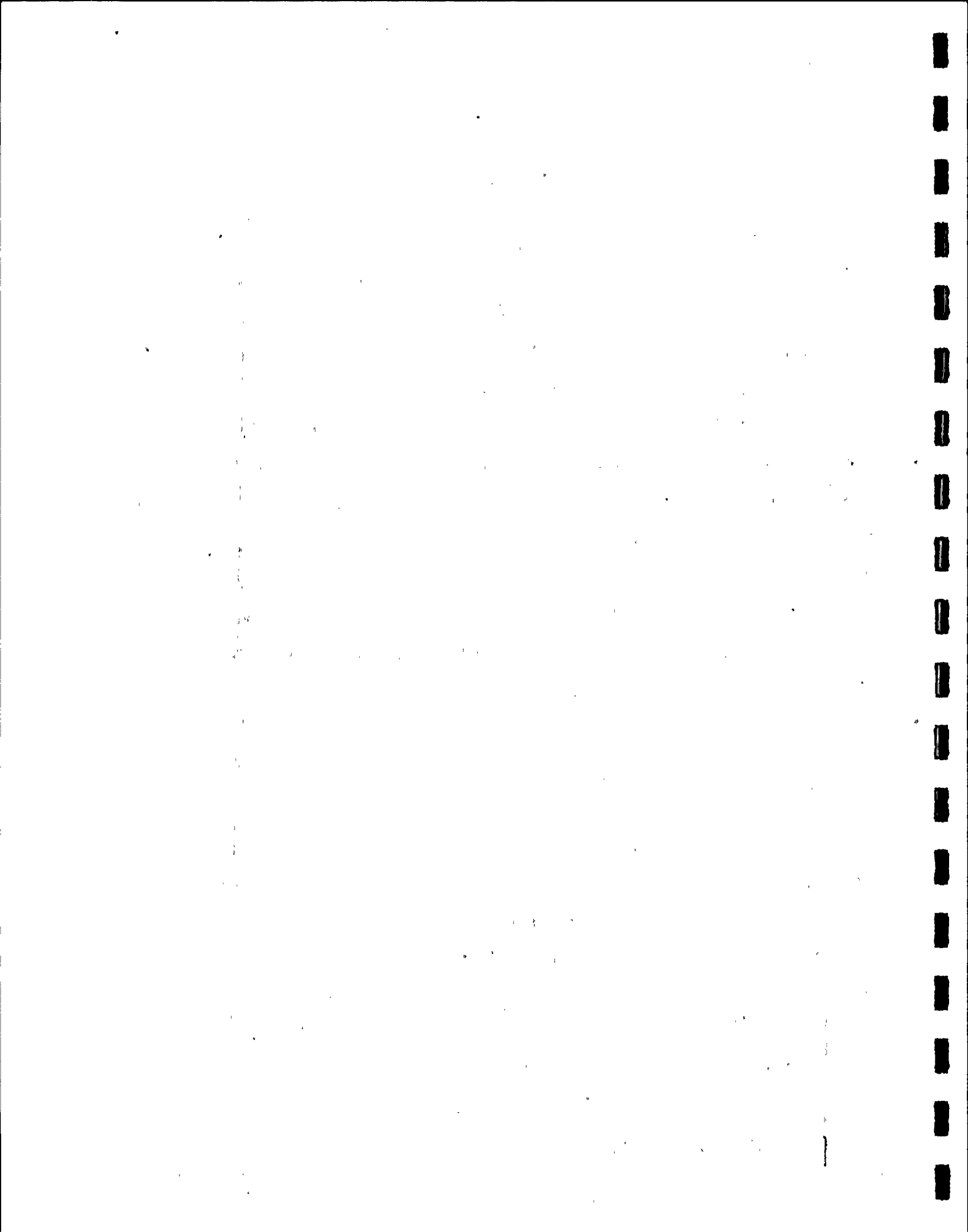


TABLE IV.A-2

Parameter (Units)	Nominal Observed Value	CE Specifications	Site Specific Specifications
(1) pH @25°C (Standard Units)	6.0	6.0 - 8.0	5.8 - 8.0
(2) Specific Conductivity (μ mhos/cm)	0.5	2.0 maximum	2.0 maximum
(3) Chloride (ppm)	<.08	0.15 maximum	0.15 maximum
(4) Sodium (ppb)	<1.0	Not Specified	10 maximum
(5) Silica (ppm)	<.01	0.02 maximum	0.02 maximum
(6) Flourides (ppm)	<0.05	0.1 maximum	0.1 maximum .

B. Power Distribution Episode Chemistry

1. Trends of Significant Chemistry Parameters

a. pH (Figures B.1 - 8)

During the period 08/04/70 to 03/31/80 including the period of the power distribution episode, the pH of the RCS was controlled within the range 5.0 - 8.0 (measured at 25°C). This range of values is consistent with the normal operating guidelines established by CE in the Reactor Plant Chemistry Manual and incorporated into RCP 1-202. Table IV.A.1 illustrates this point. A nominal value for pH during the power distribution episode would be 6.5.

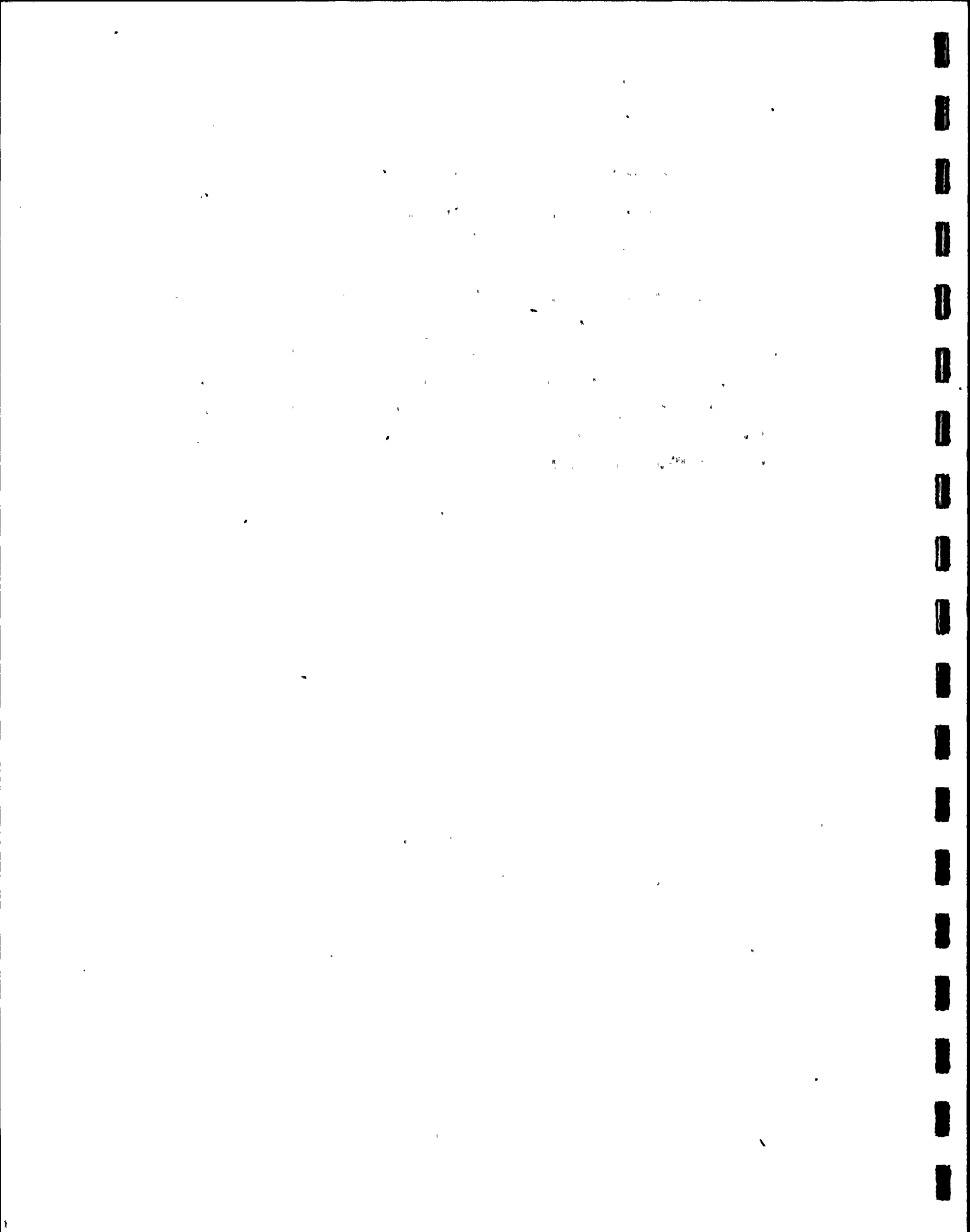
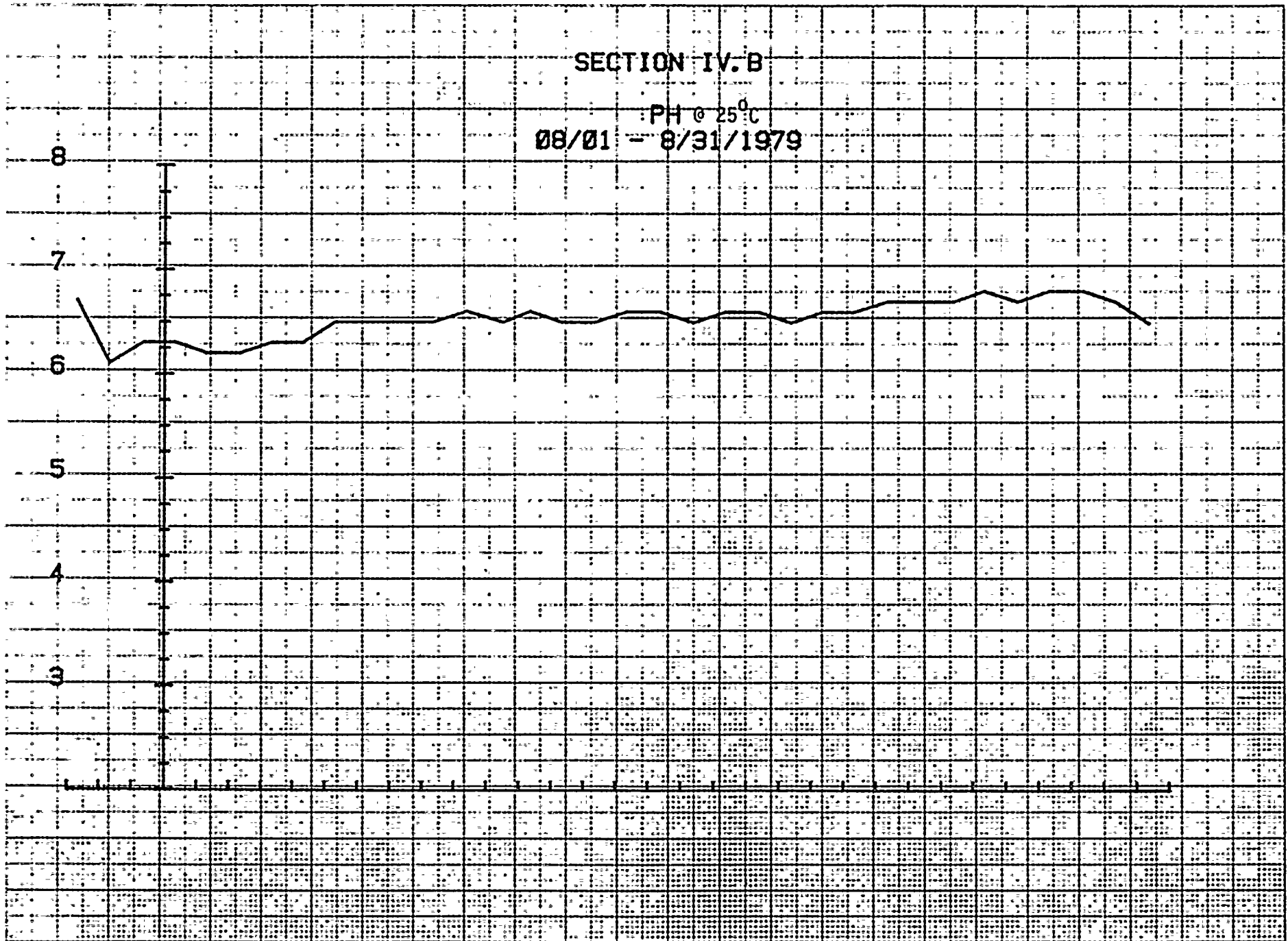


FIGURE B.1

SECTION IV.B

PH @ 25°C
08/01 - 8/31/1979

54



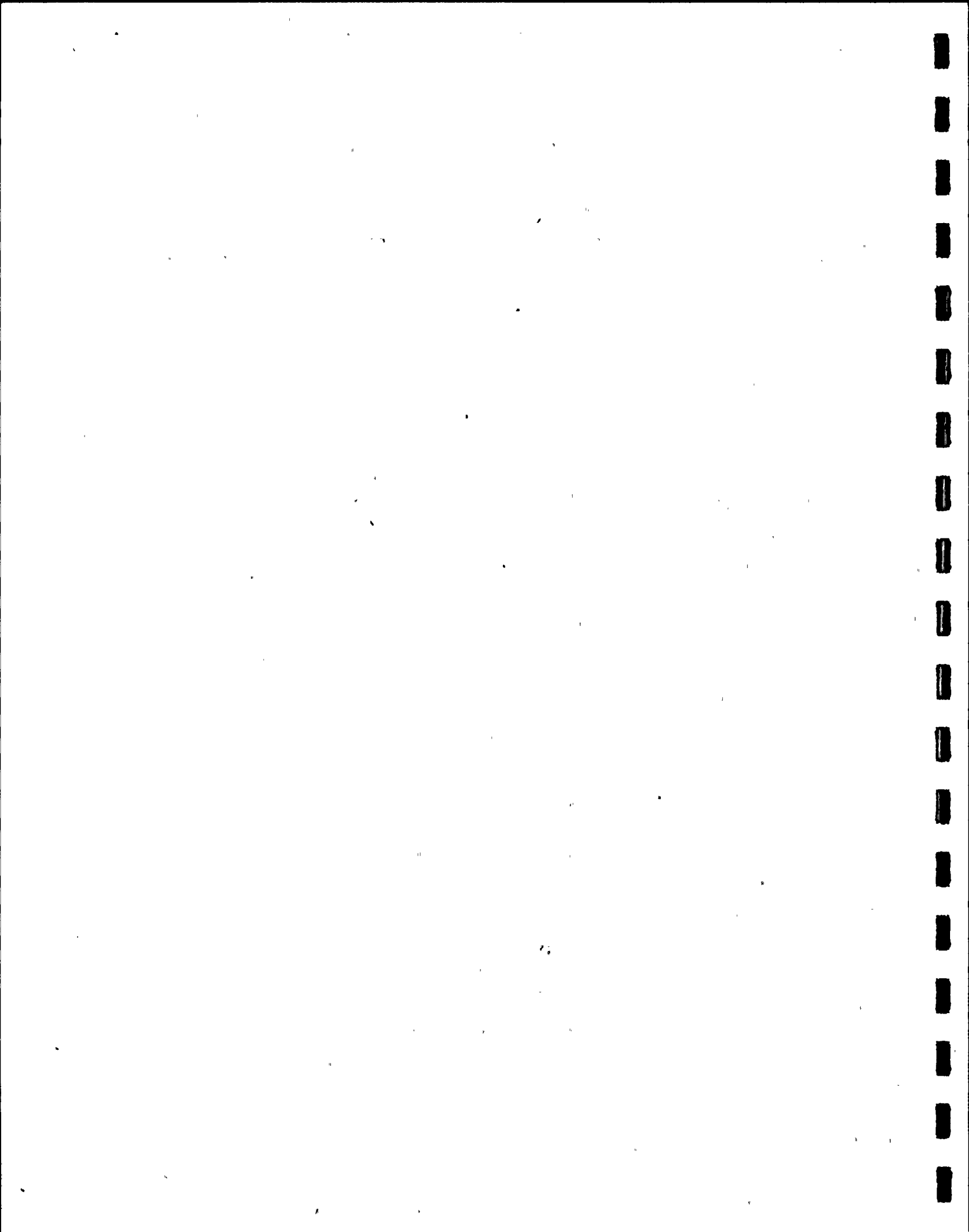


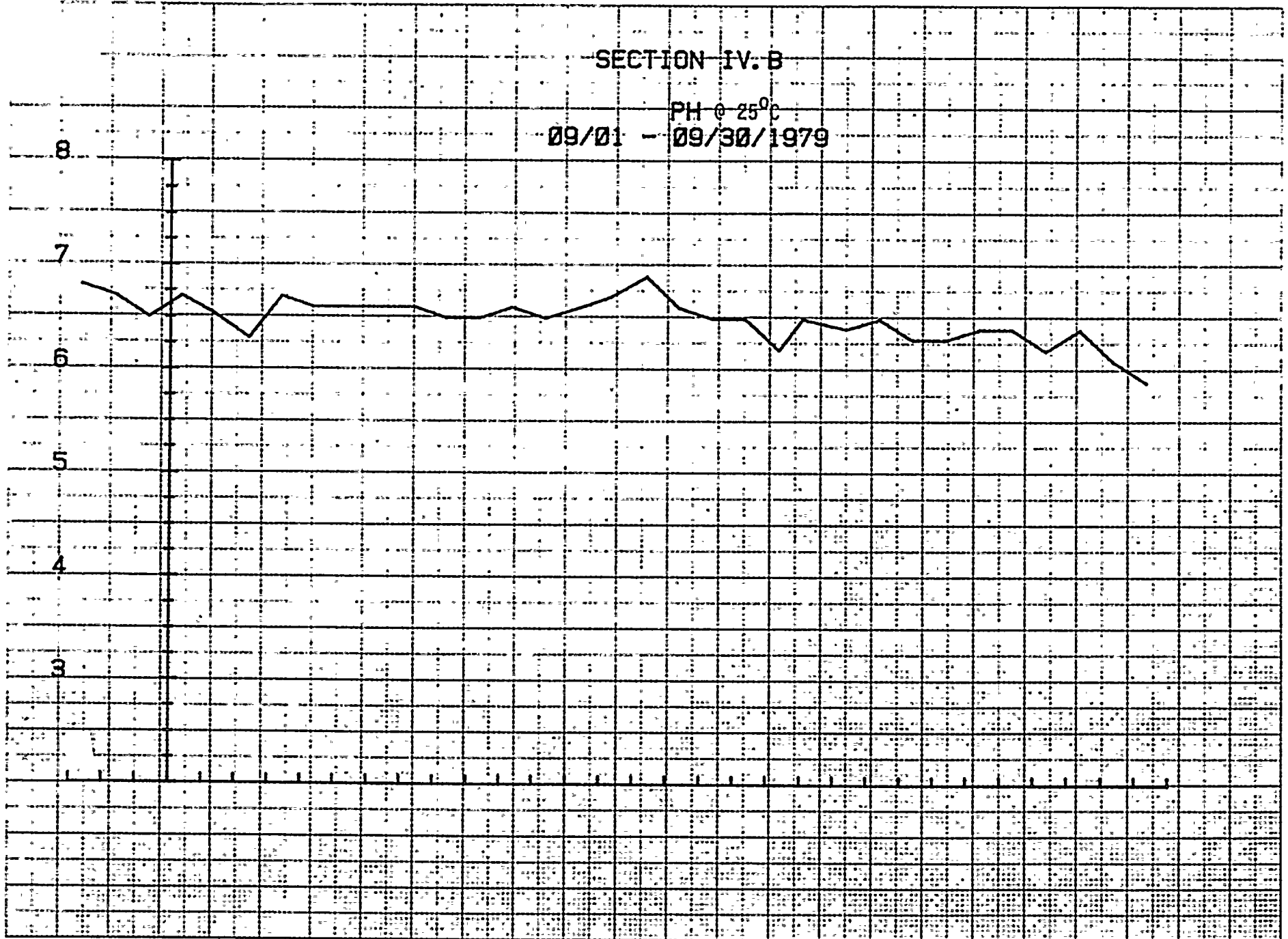
FIGURE B.2

SECTION IV. B

PH @ 25°C

09/01 - 09/30/1979

55



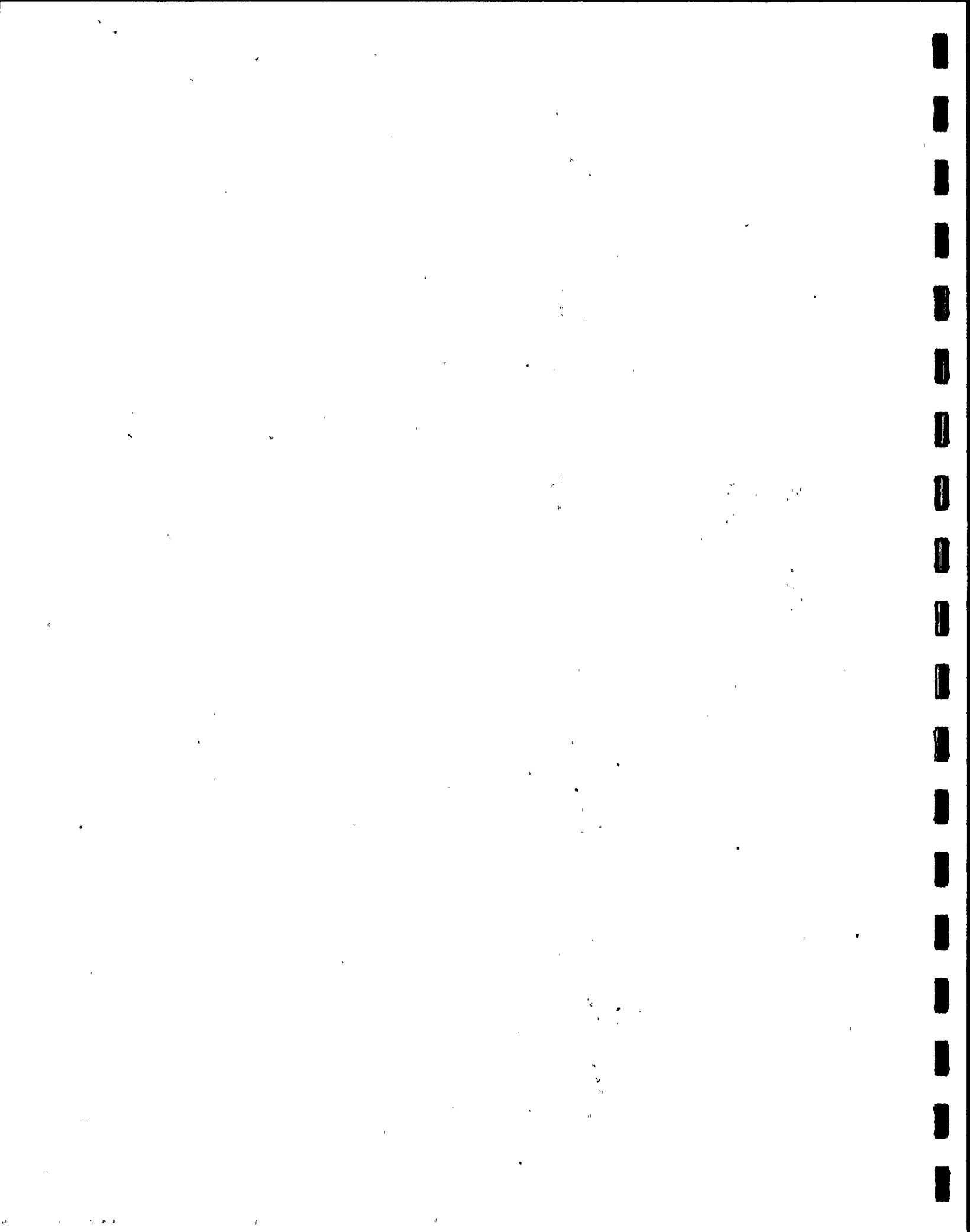
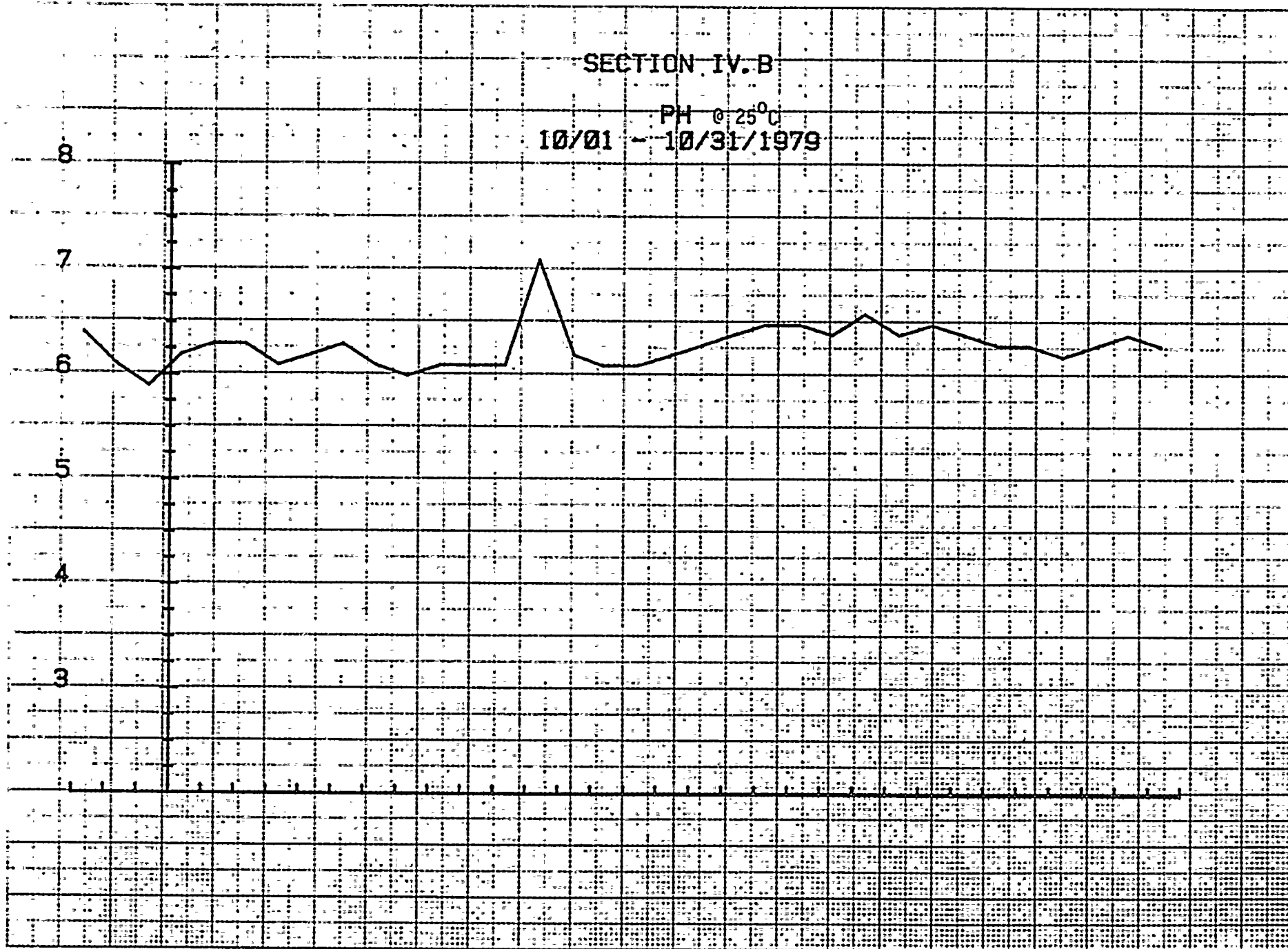


FIGURE B.3

SECTION IV. B

PH @ 25°C
10/01 - 10/31/1979

56



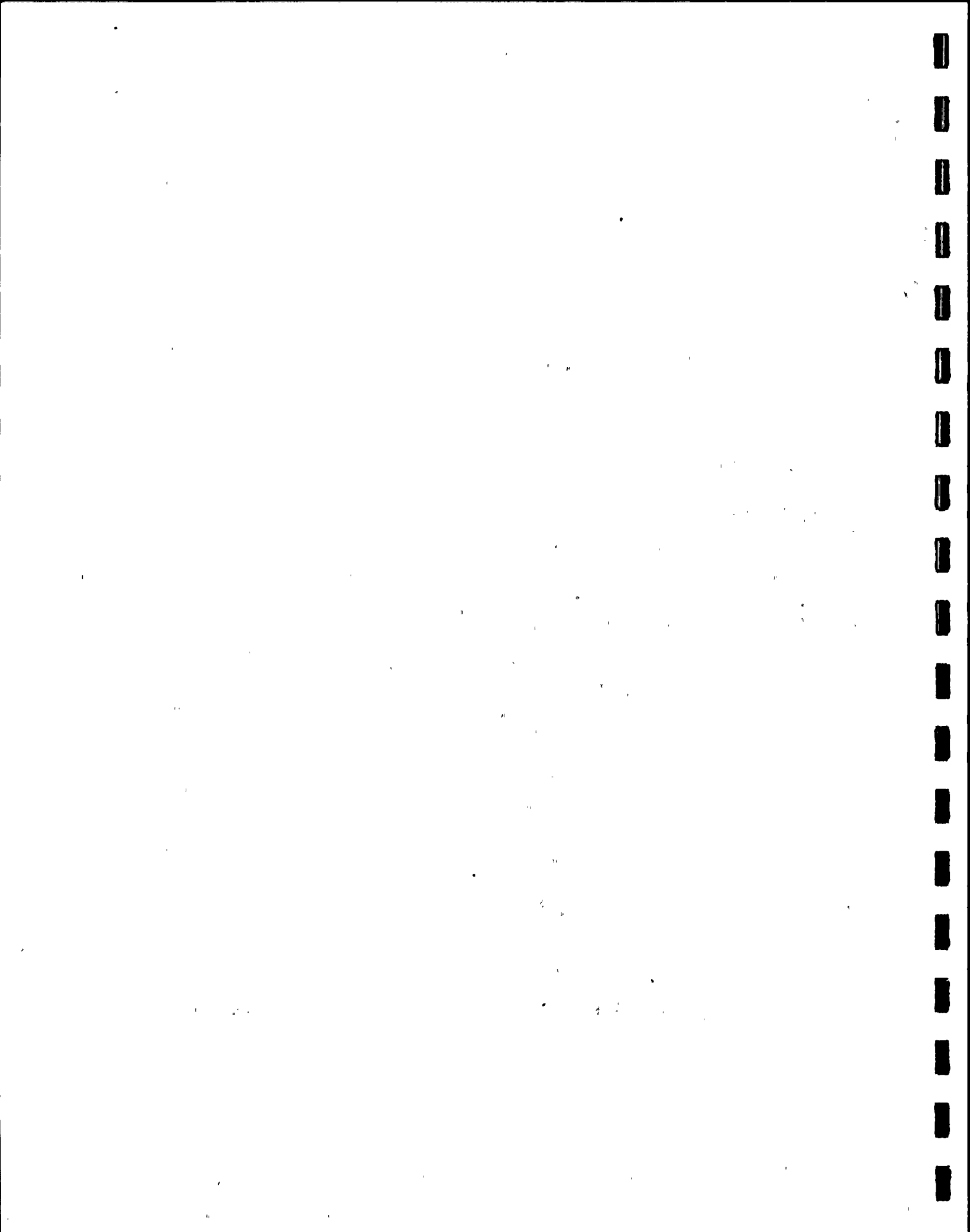


FIGURE B.4

SECTION IV. B

PH @ 25°C

11/01 - 11/30/1979

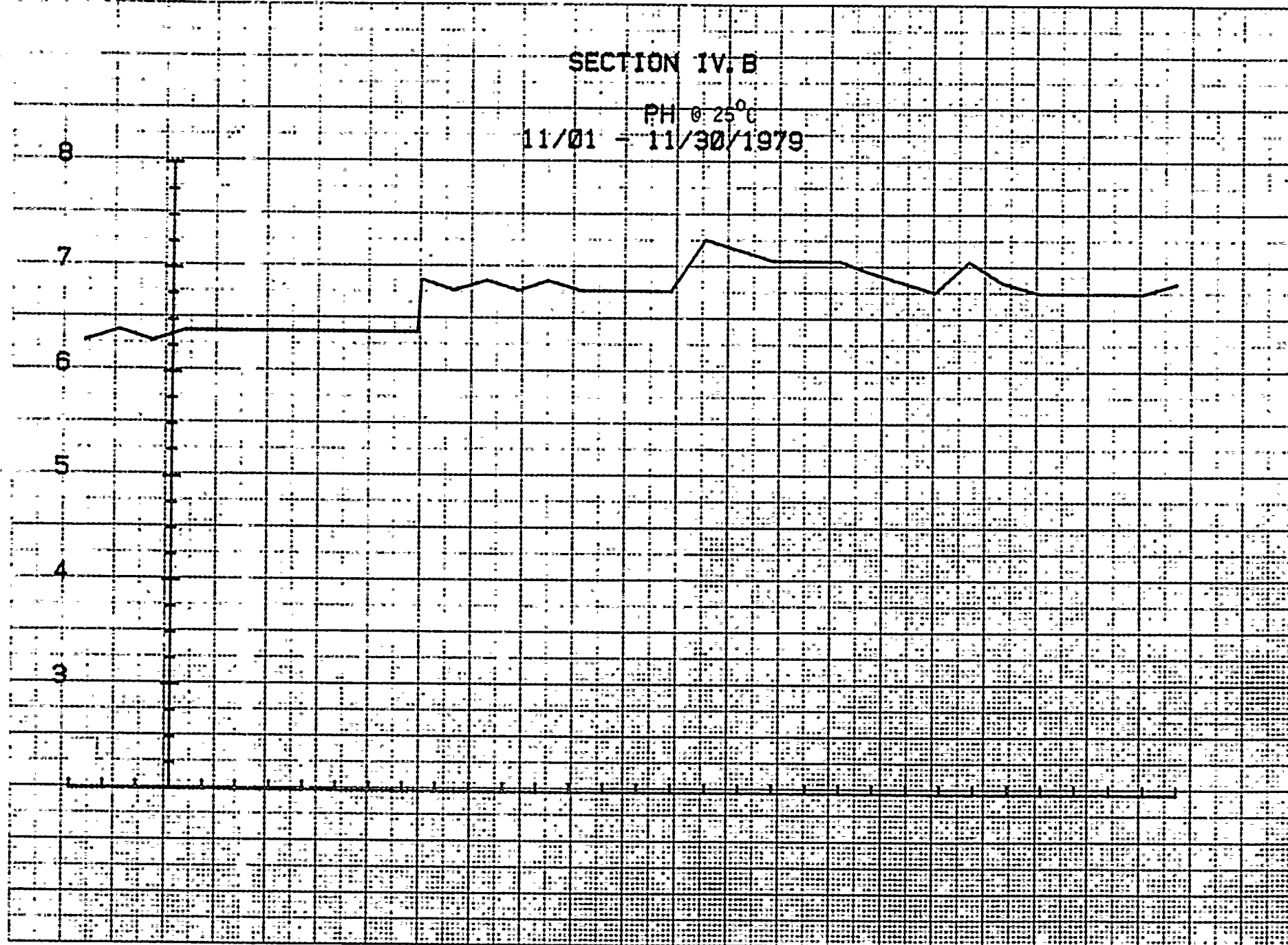
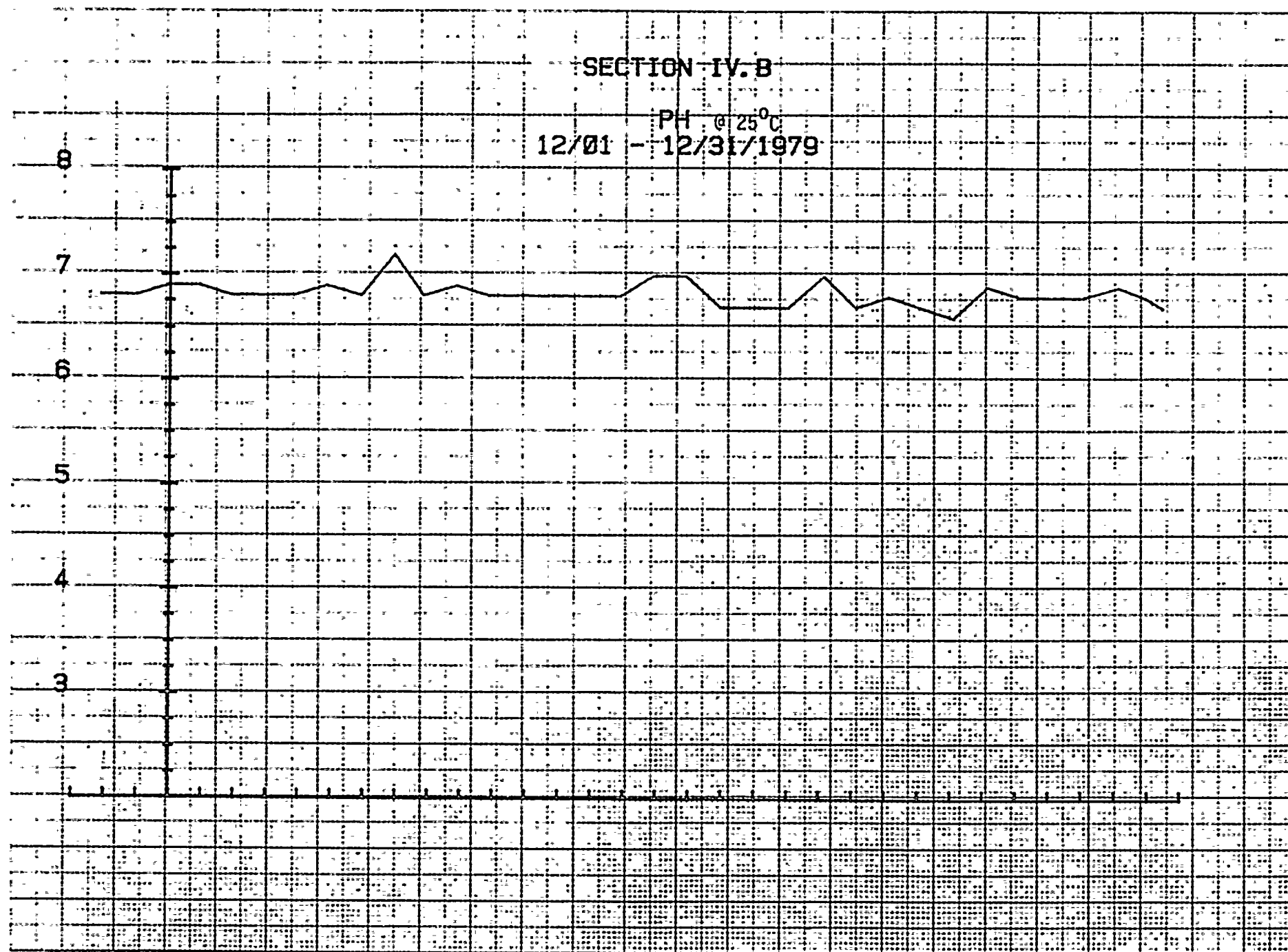


FIGURE B.5

SECTION IV.B

PH @ 25°C
12/01 -- 12/31/1979



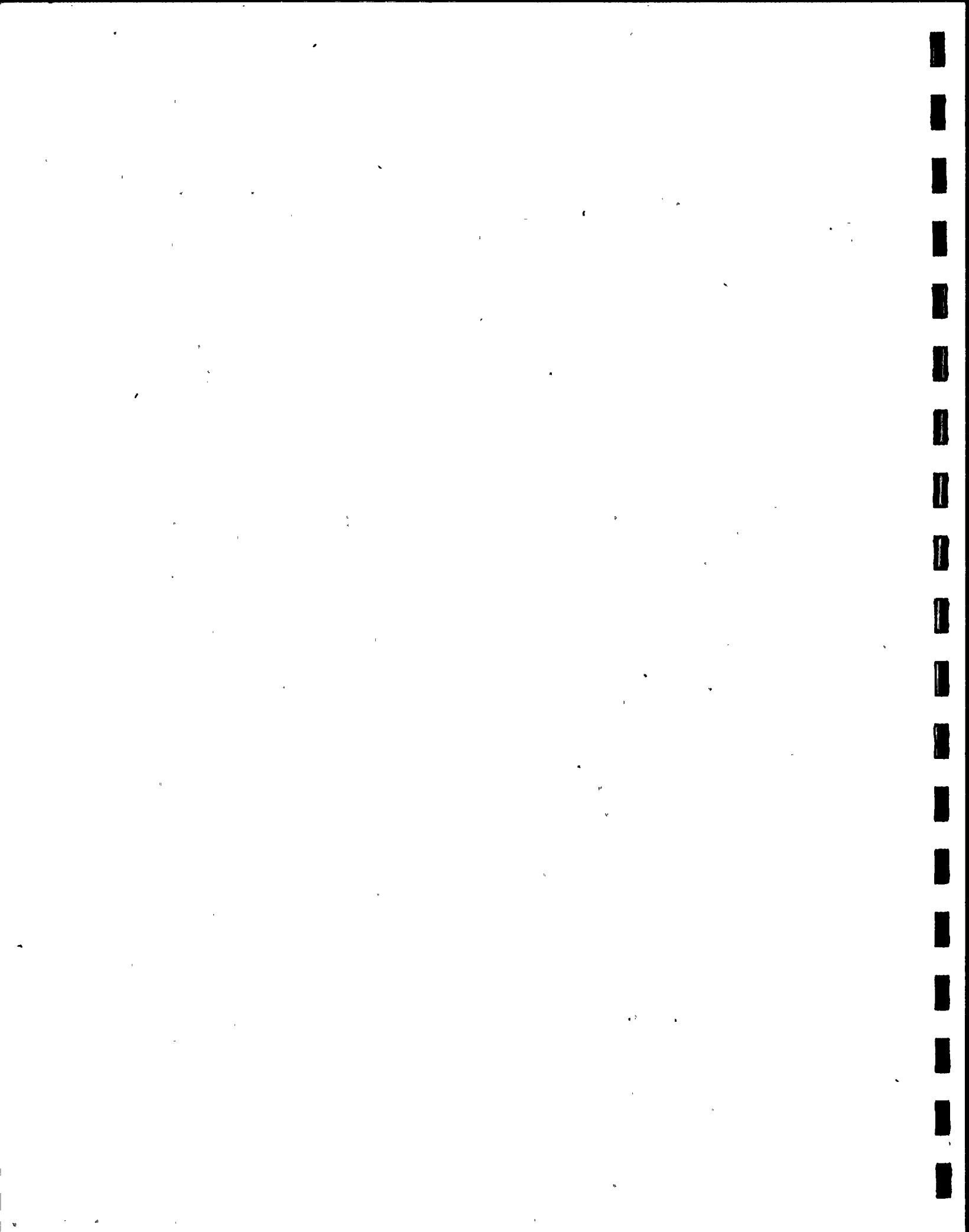
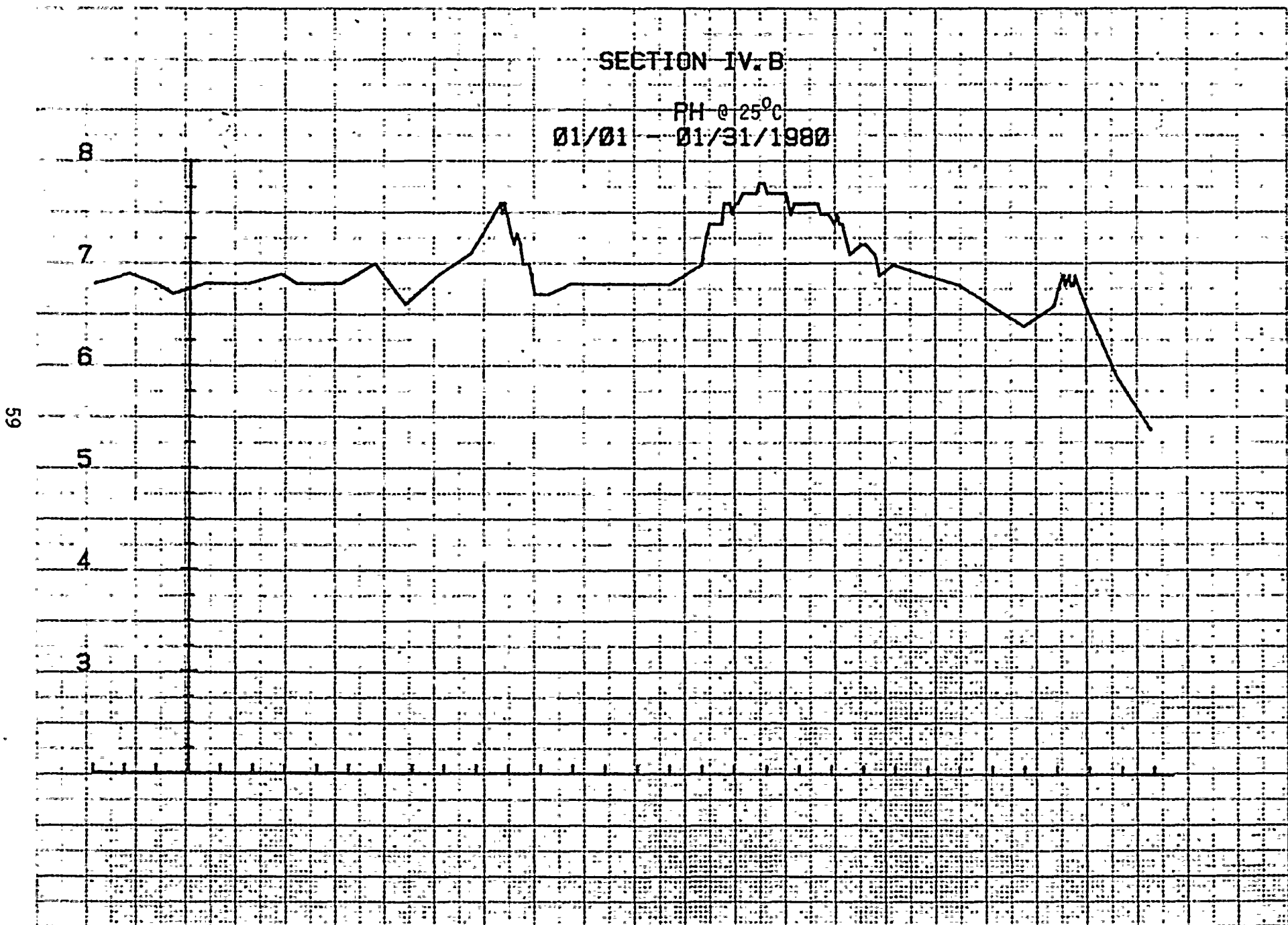


FIGURE B.6



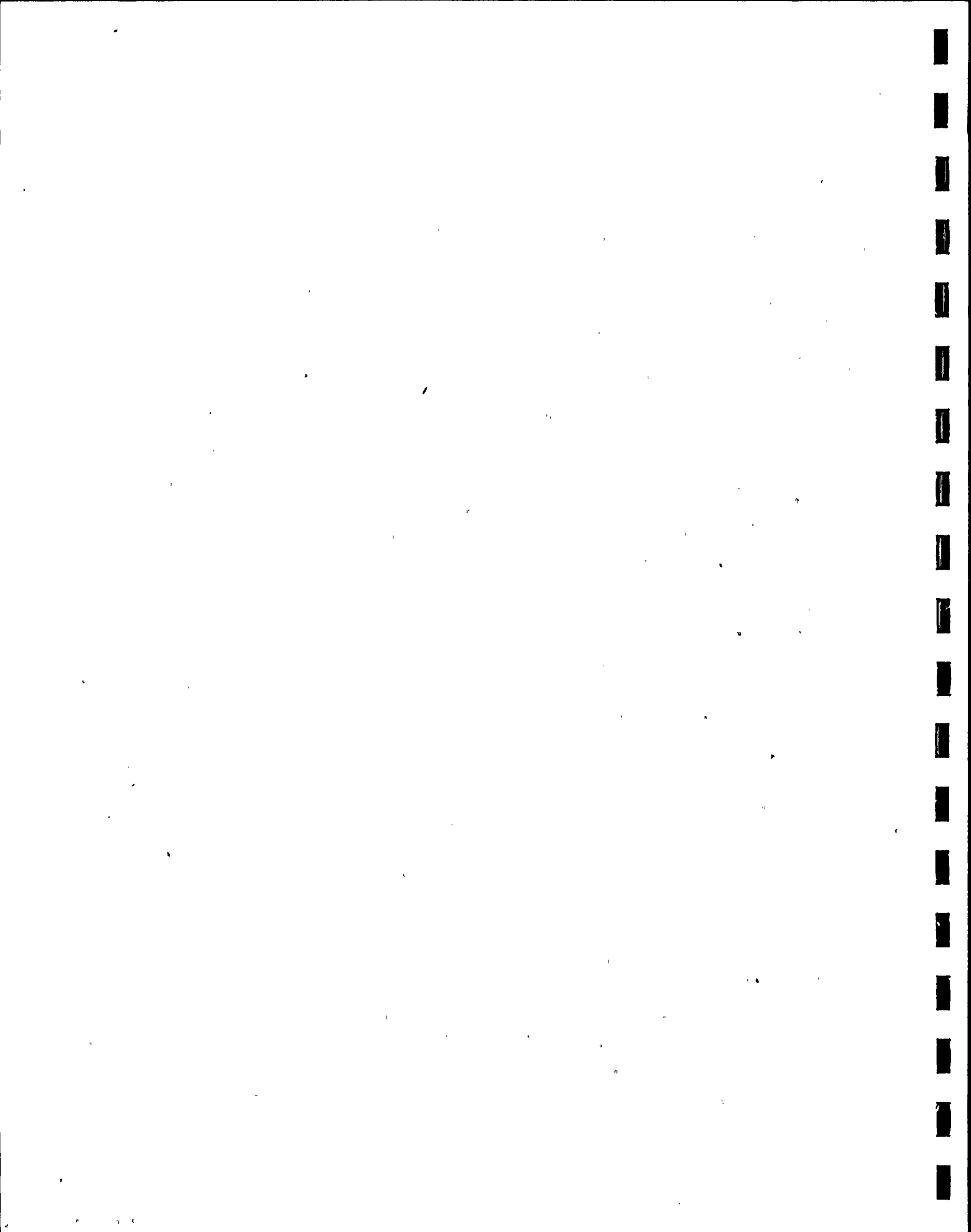


FIGURE B.7

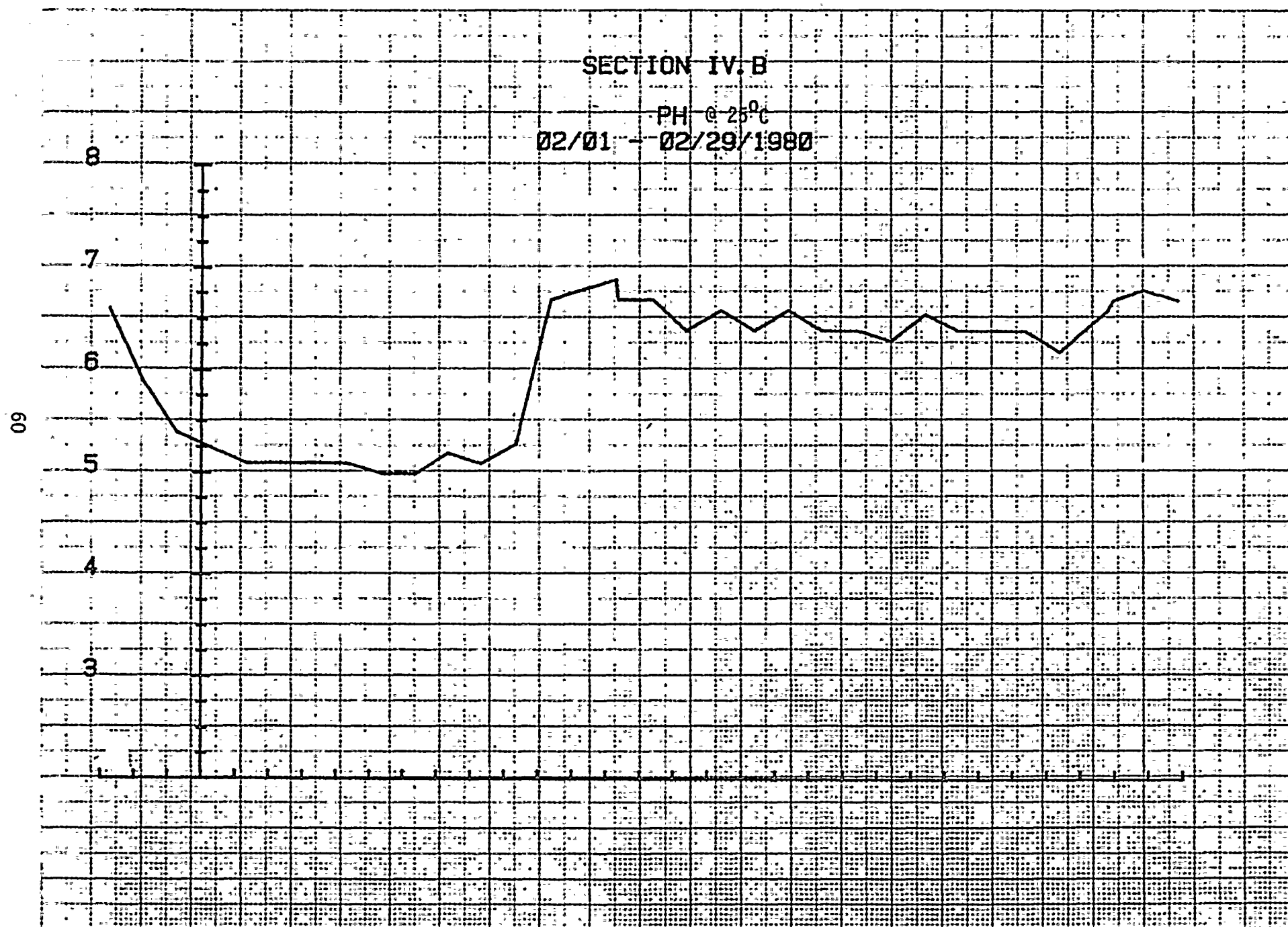
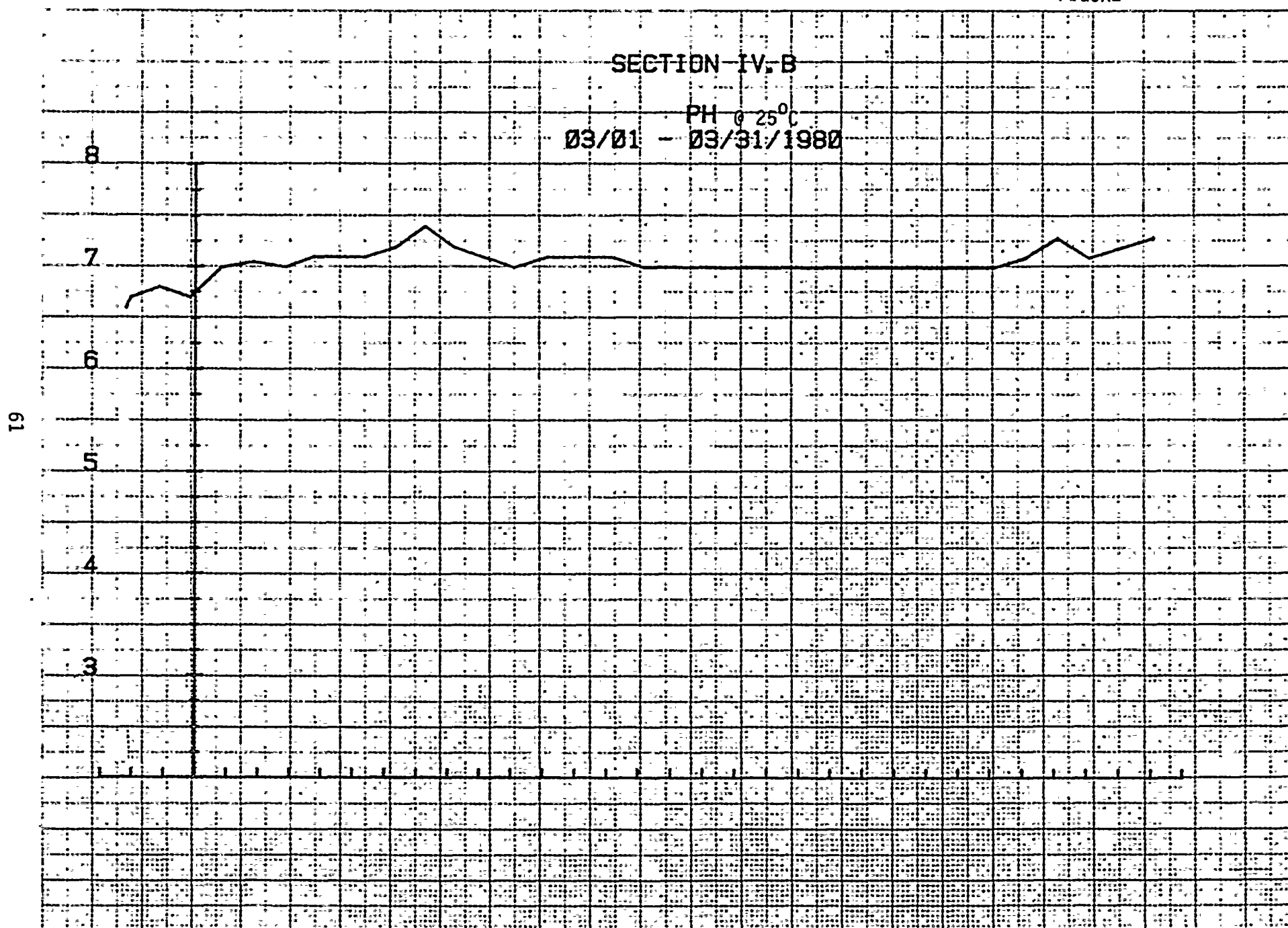


FIGURE B.8



b. Conductivity (Figures B.9-16)

The specification regarding RCS conductivity is that the values be consistent with coolant additives. Under normal operating conditions, the reactor coolant contains only boric acid and lithium hydroxide chemical additives in significant concentrations. During the initial stages of the power distribution episode RCS conductivity was controlled to within the specification noted in Table IV.A.1 in that conductivity was consistent with pH and boron concentration. In response to a CE recommendation, hydrazine injection to the RCS was initiated during normal operation. Whereas conductivity previously ranged from 10-20 μ mhos/cm, new data points were in agreement with the concentration of chemical additives in the RCS. The increase in baseline conductivity caused by ammonia decomposition products of hydrazine was anticipated. There were several occasions during the power distribution episode where significant conductivity increases in the RCS were initiated by the injection of excessive quantities of N_2H_4 into the CVCS. These out-of-trend conductivity values (i.e. 1/10/79 conductivity-160 mhos/cm) are discussed in Section IV.B.2.6. It should be noted that conductivity was at all times consistent with the concentration of chemical additives (boric acid, lithium hydroxide, and hydrazine) in the RCS and that the introduction of impurities was not a problem during the power distribution.



FIGURE B.9

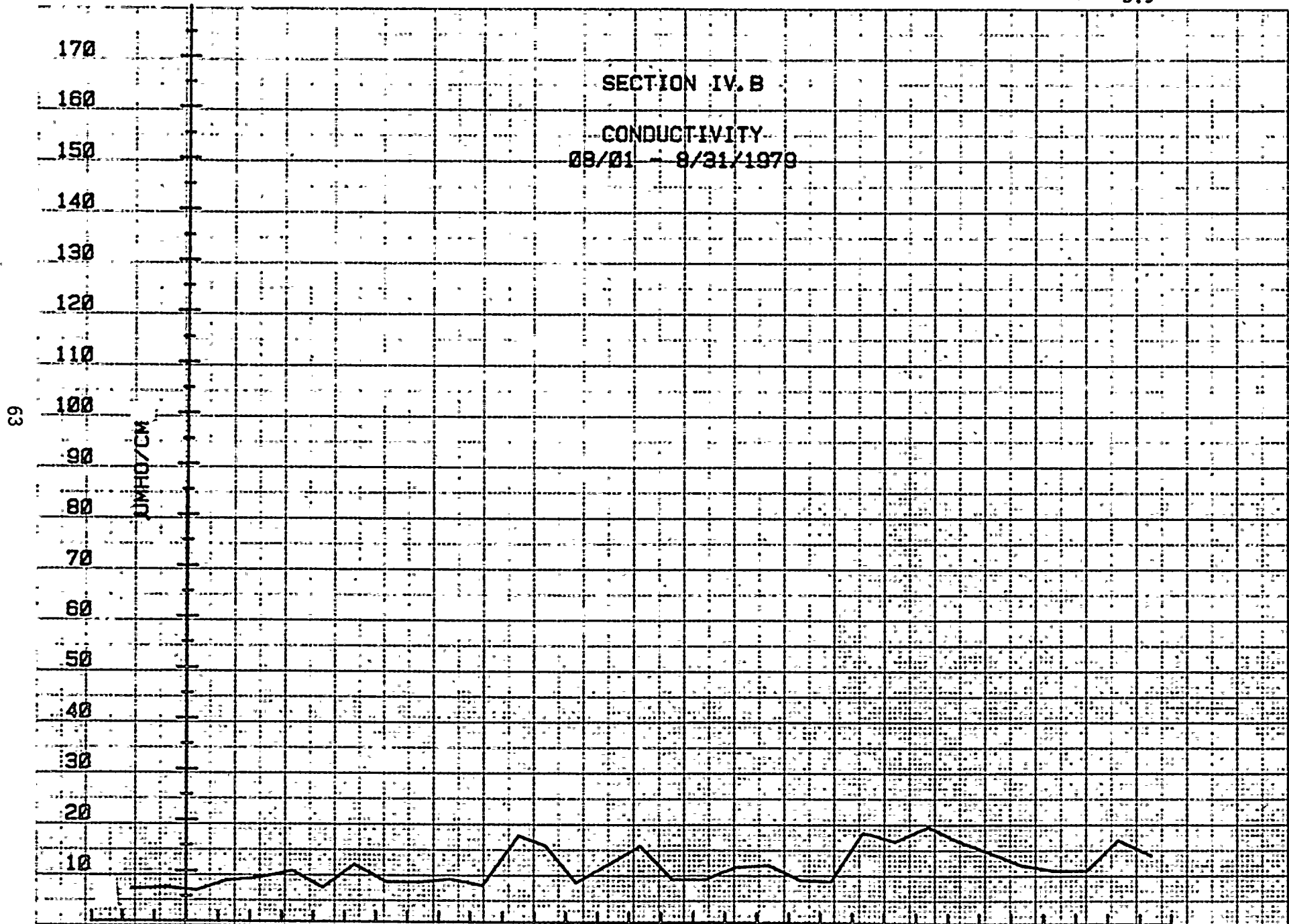




FIGURE B.10

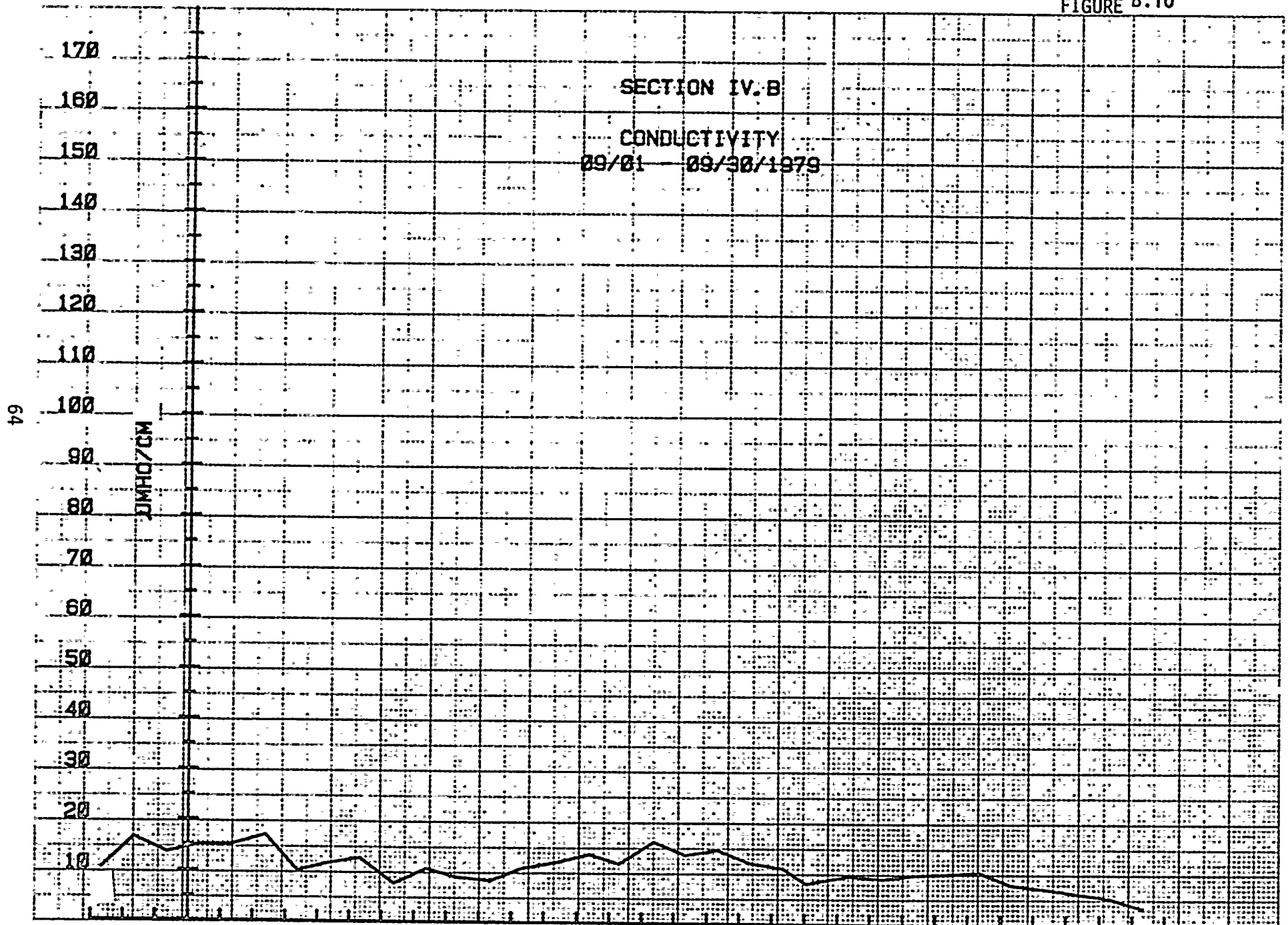




FIGURE B.11

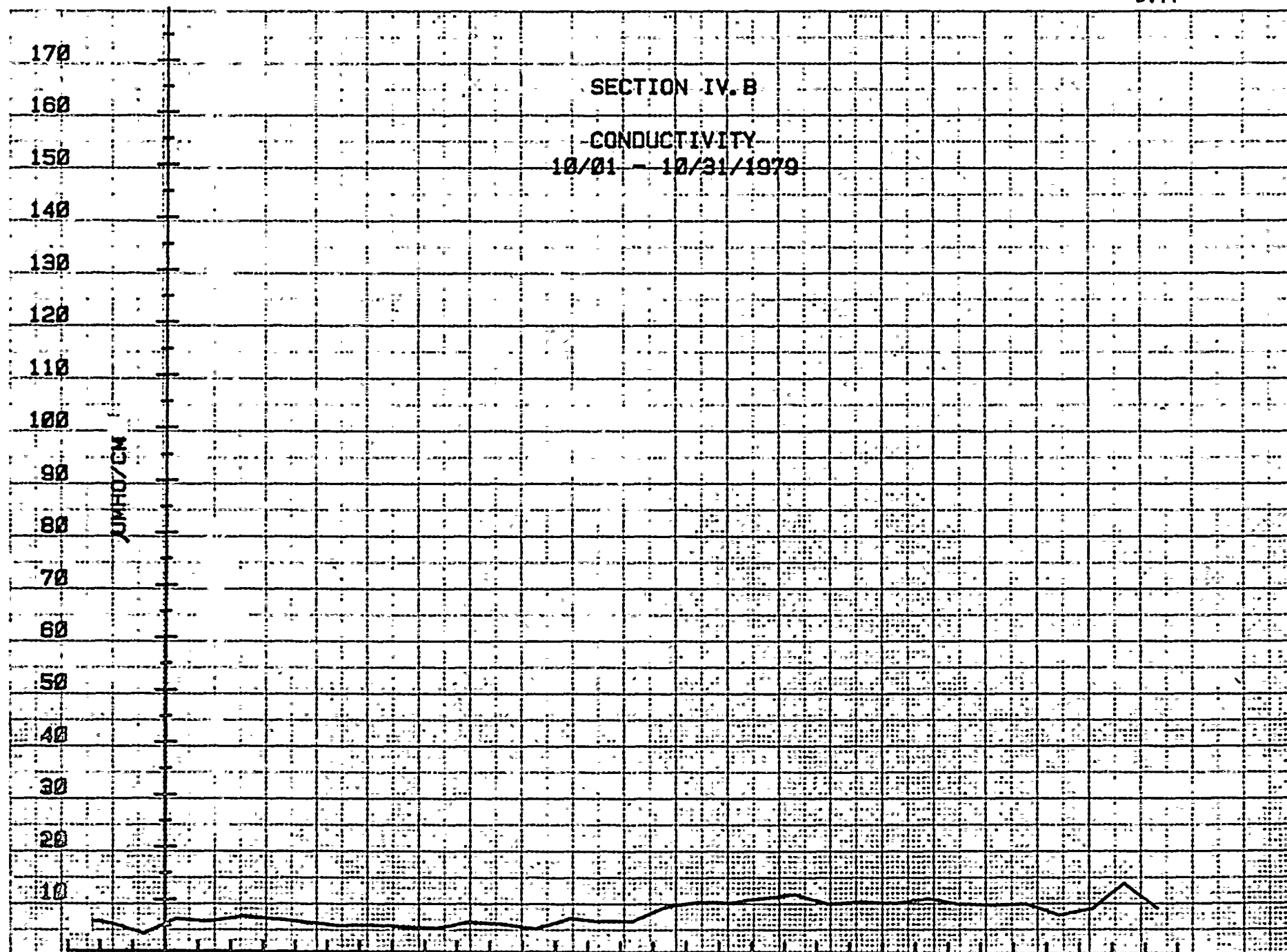


FIGURE B.12

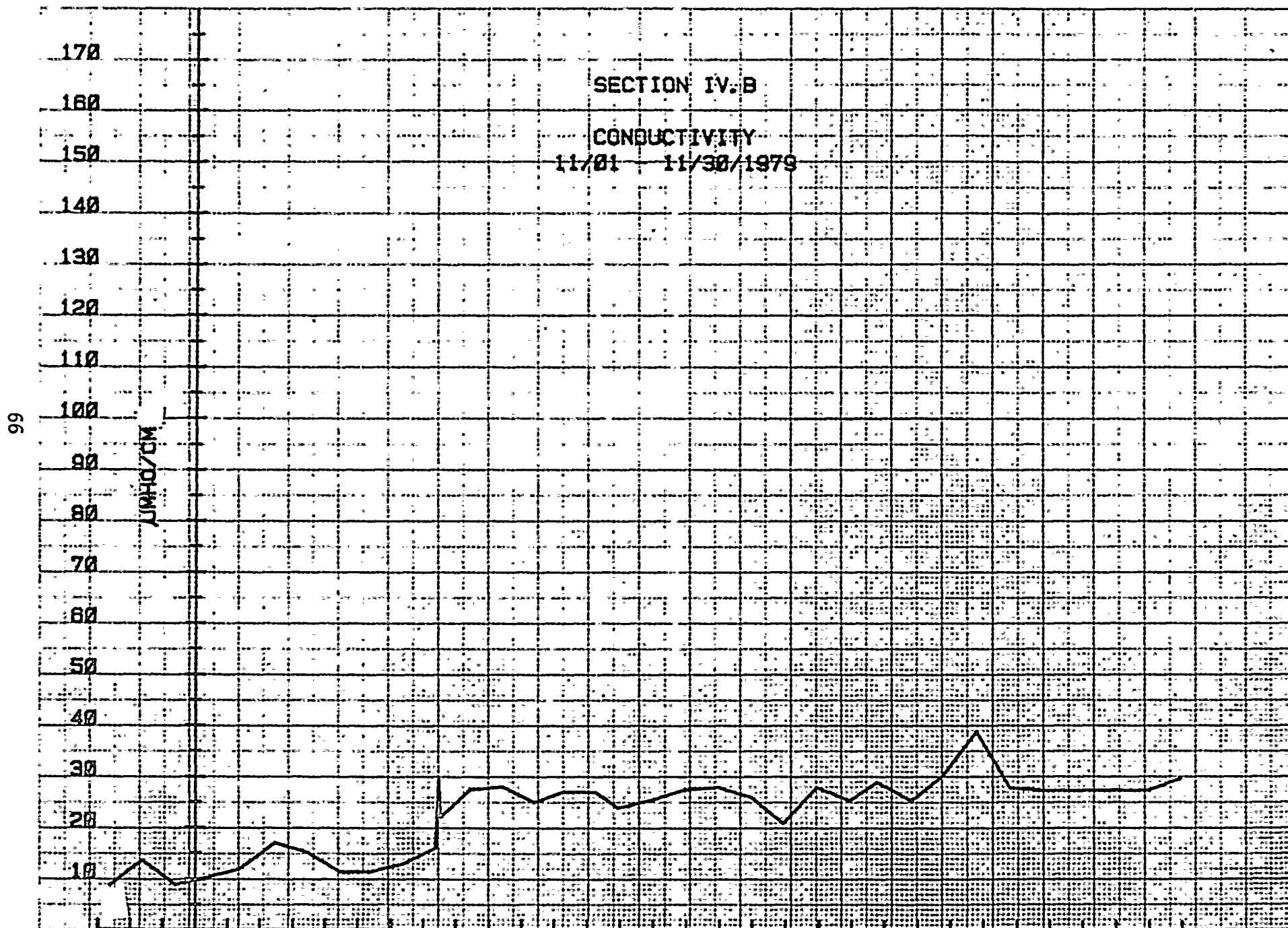




FIGURE B.13

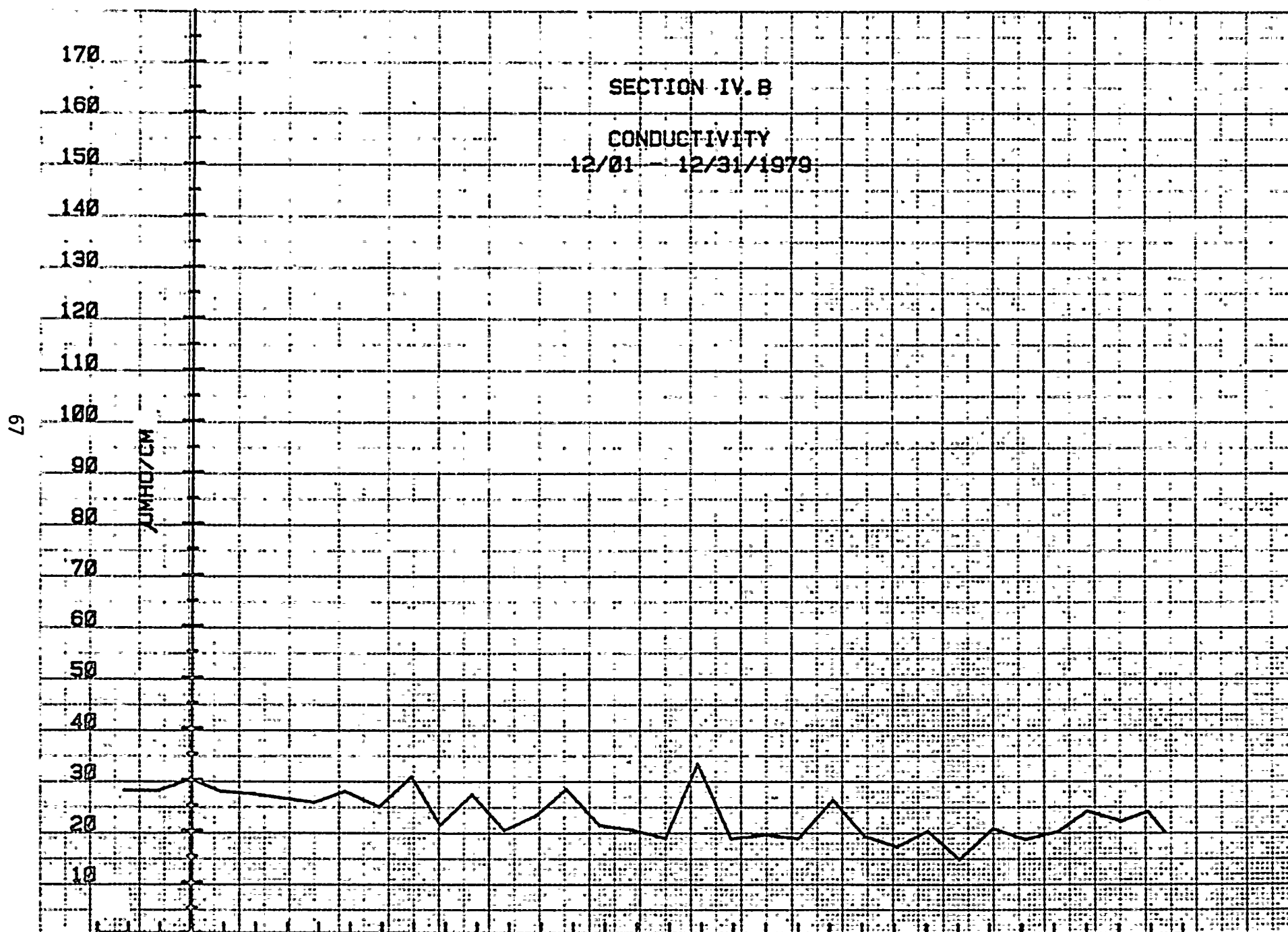




FIGURE B.14

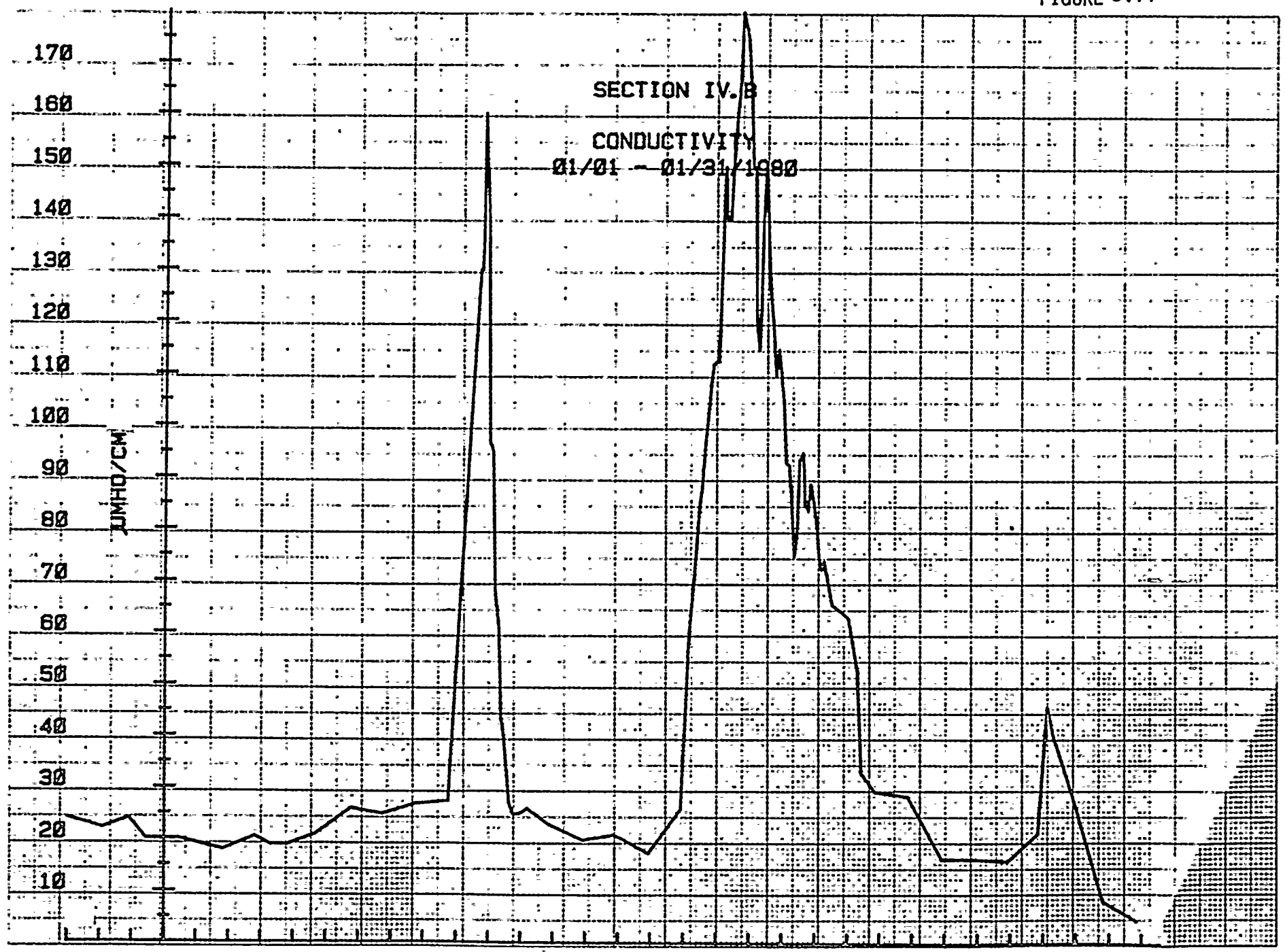
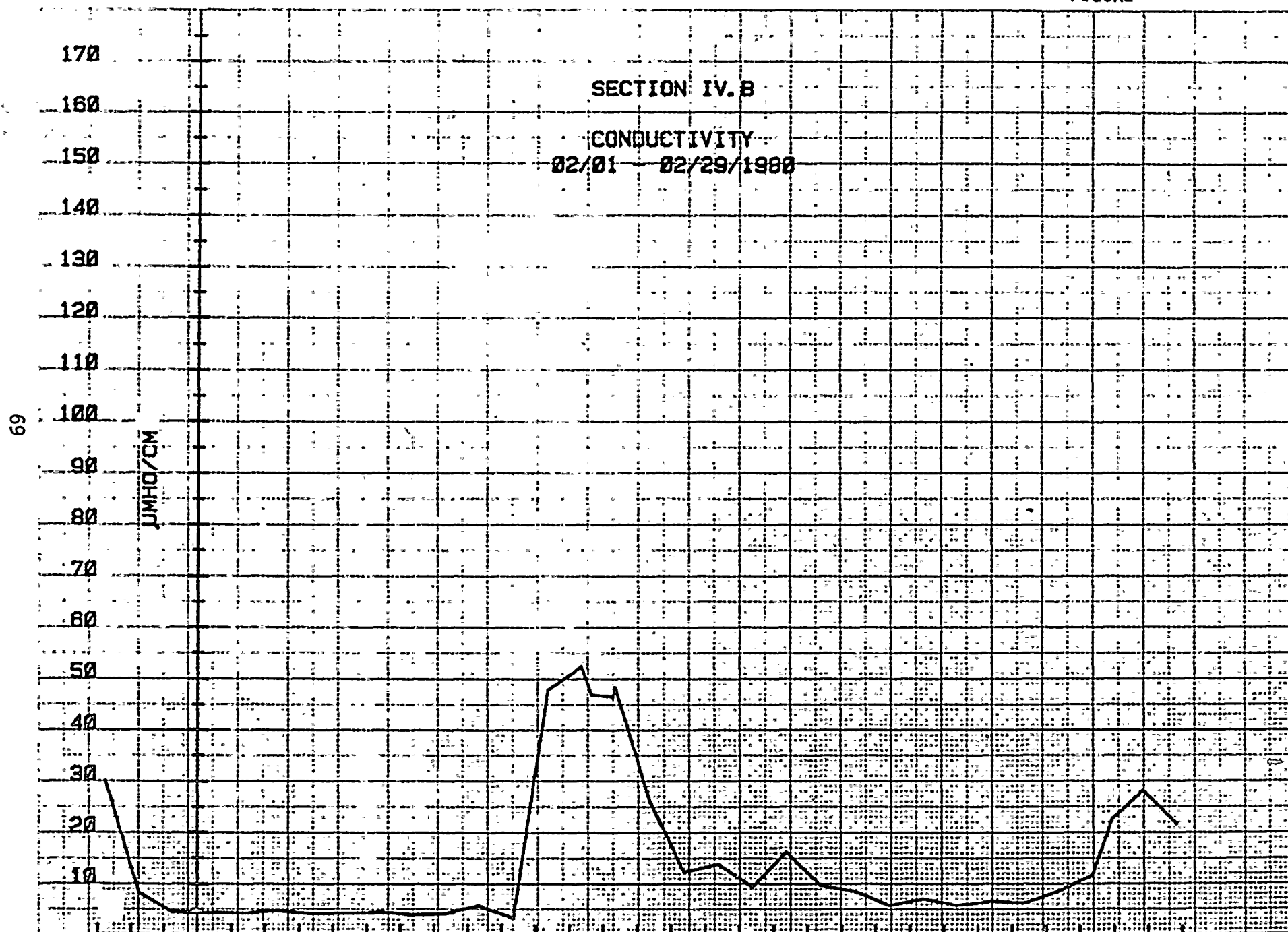




FIGURE B.15



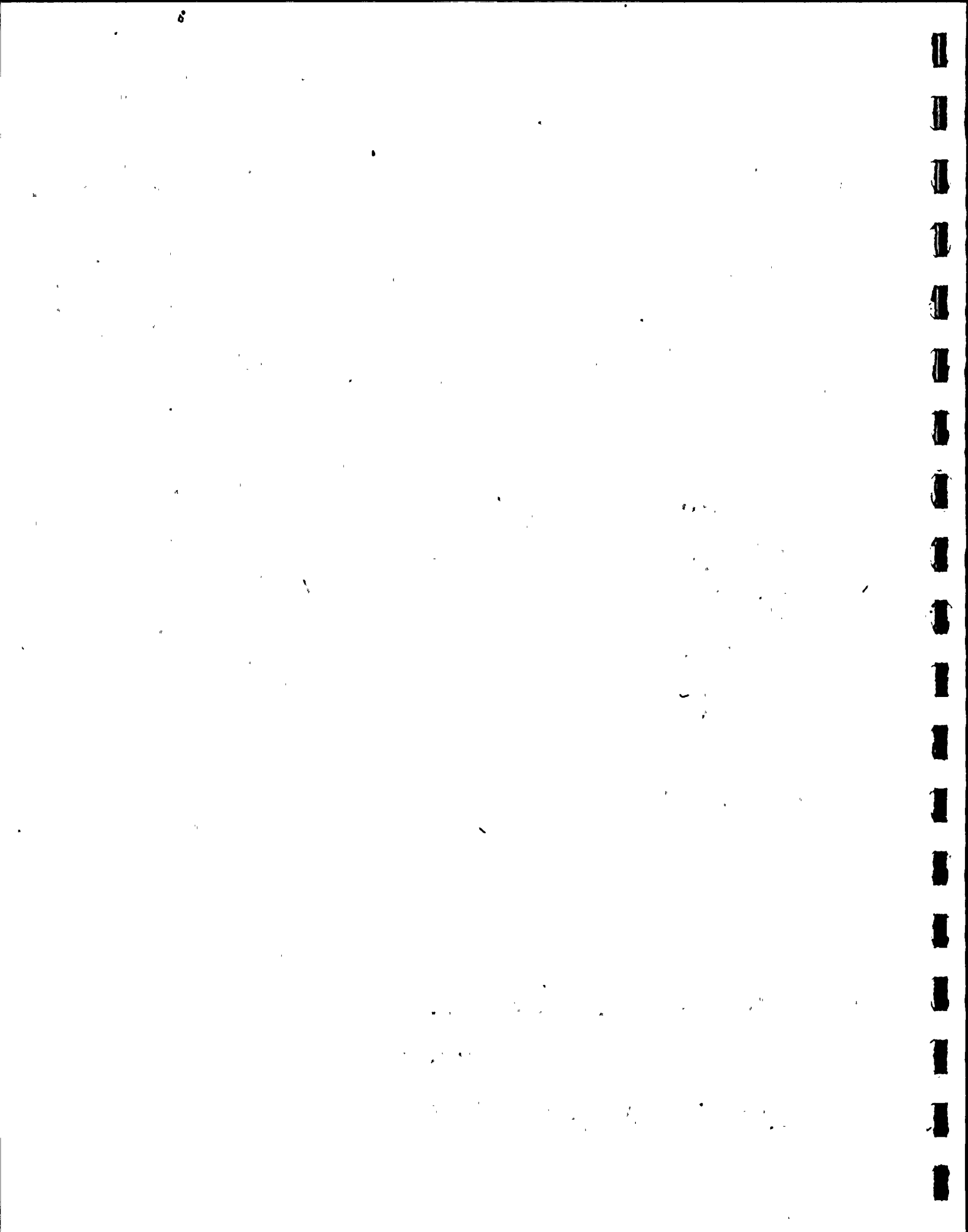
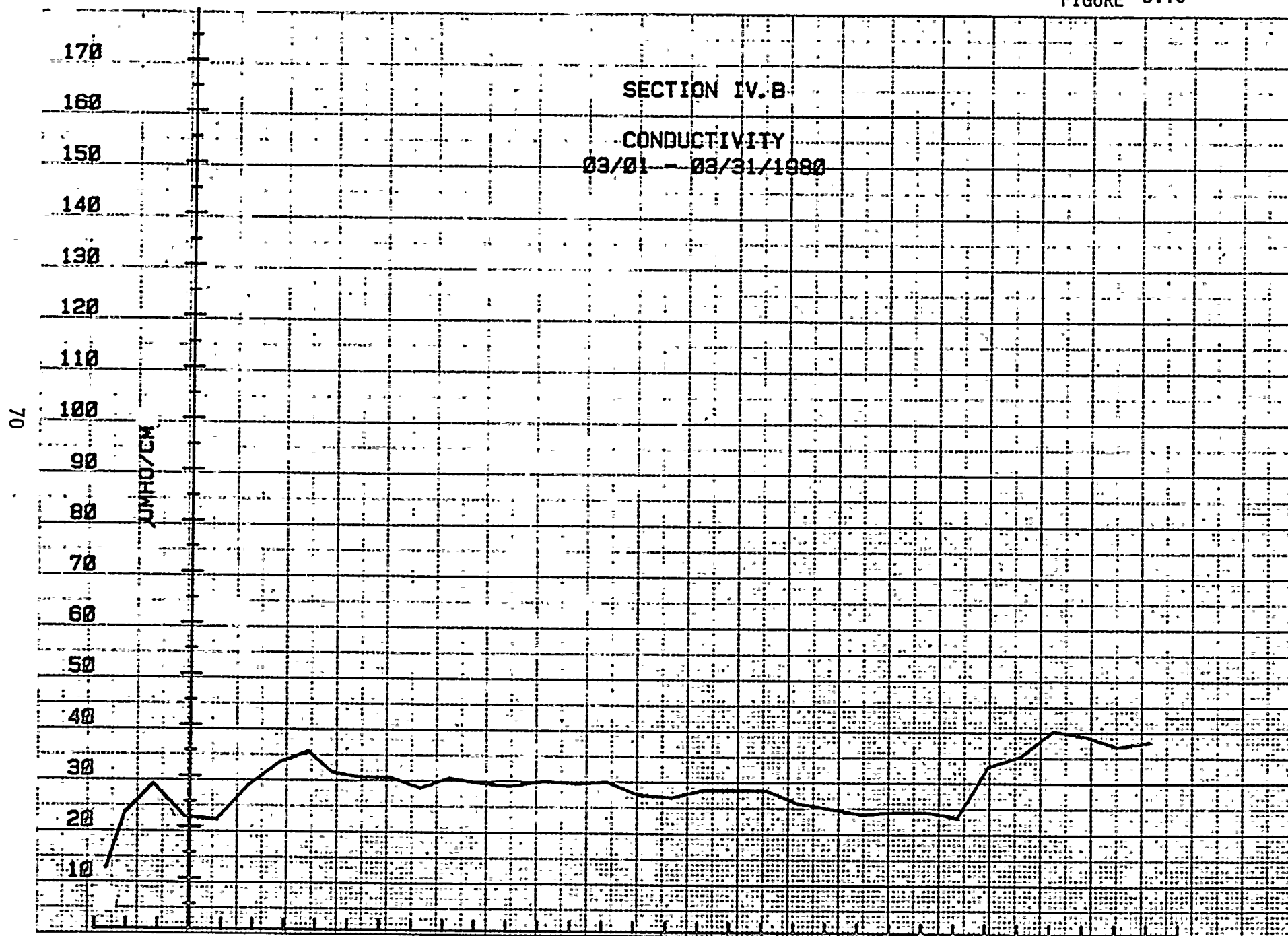


FIGURE B.16



c. Lithium (Figures B.17-24)

In accordance with CE guidelines, the site specific limitation for lithium in the RCS is 1.0 ppm maximum (Reference Table IV.A.1). During the initial portion of the power distribution episode, the lithium concentration was maintained within this guideline (Figures B.17, B.18 and B.19). However, in early November the lithium concentration was increased to approximately 2.0 ppm pursuant to a CE recommendation to maintain lithium concentration as high as possible but less than 2.2 ppm. With the noticeable exception of January 10, 1980, the lithium concentration was controlled to approximately the CE guidelines. The RCS lithium concentration increase of January 10, 1980 is discussed in Section IV.B.2.a.

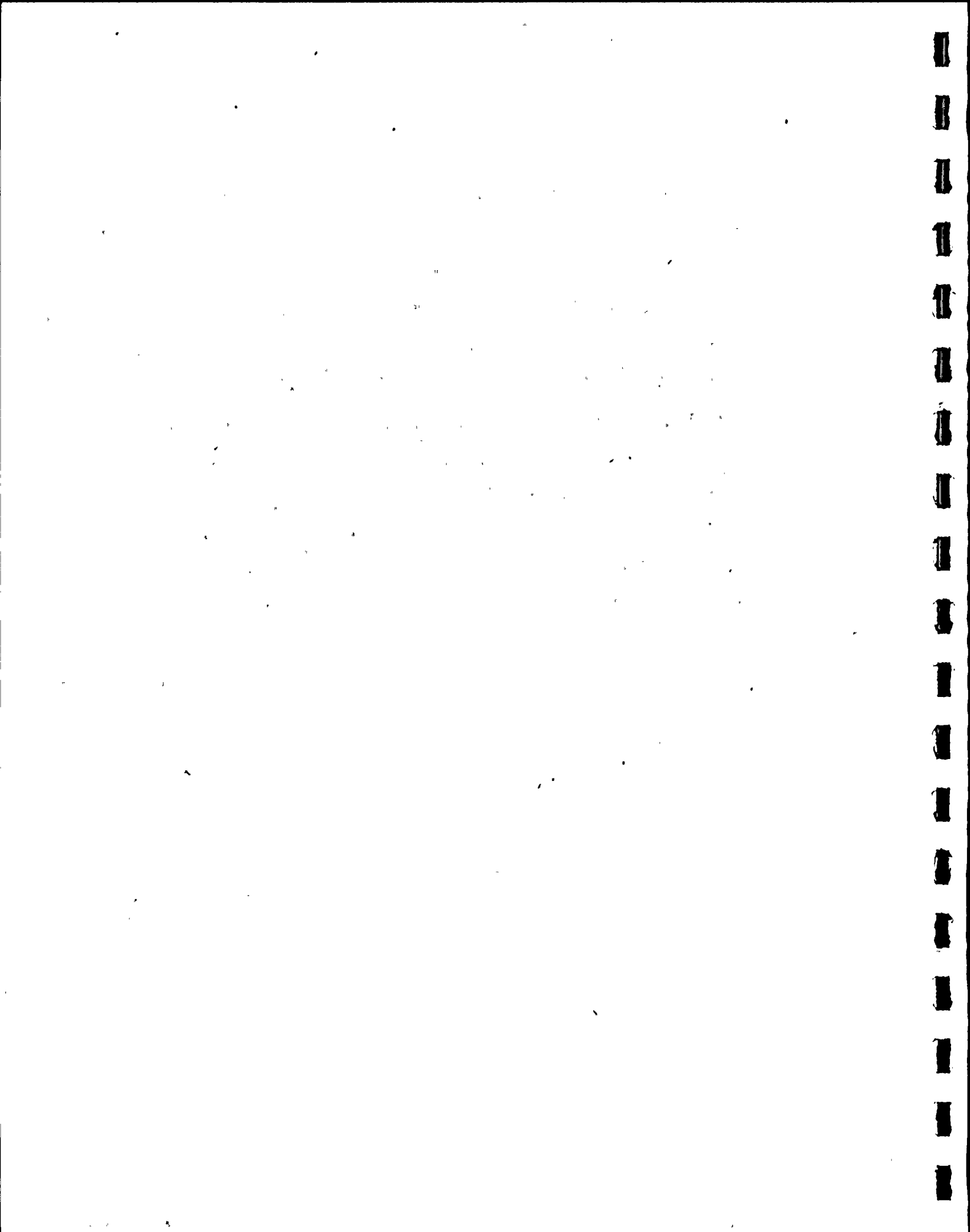


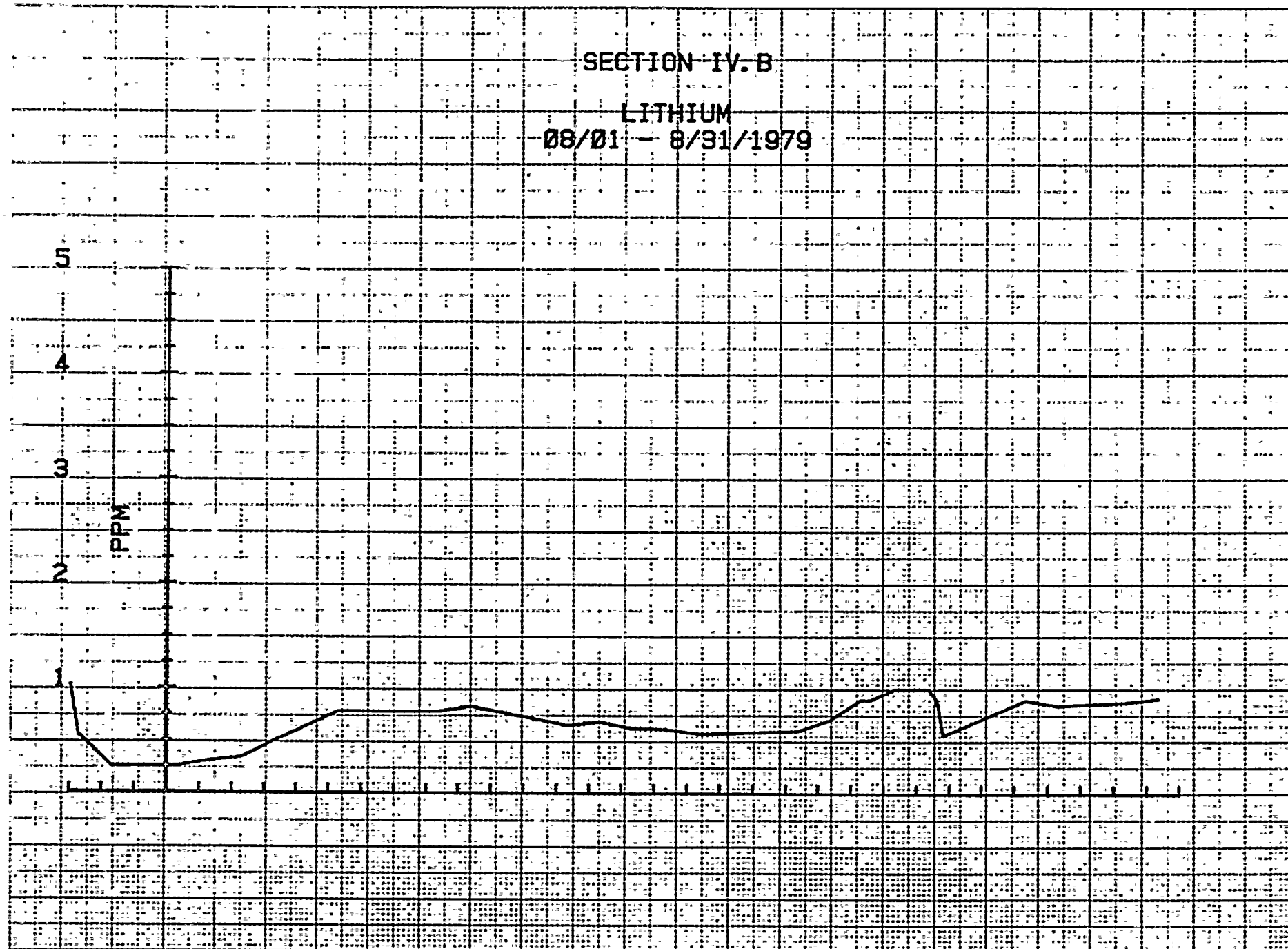
FIGURE B.17

SECTION IV. B

LITHIUM

08/01 - 8/31/1979

72



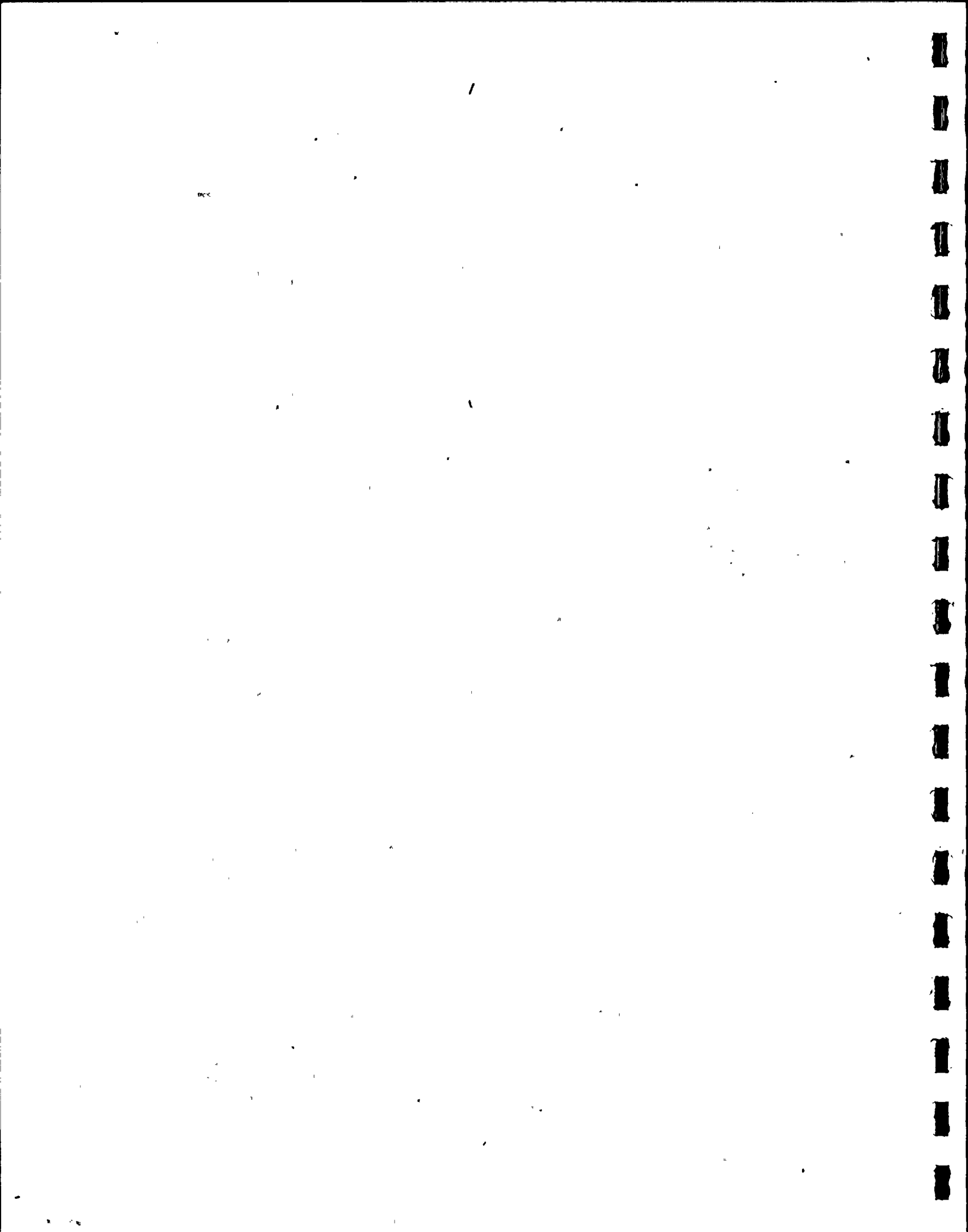


FIGURE B.18

SECTION IV.B

LITHIUM

09/01 - 09/30/1979

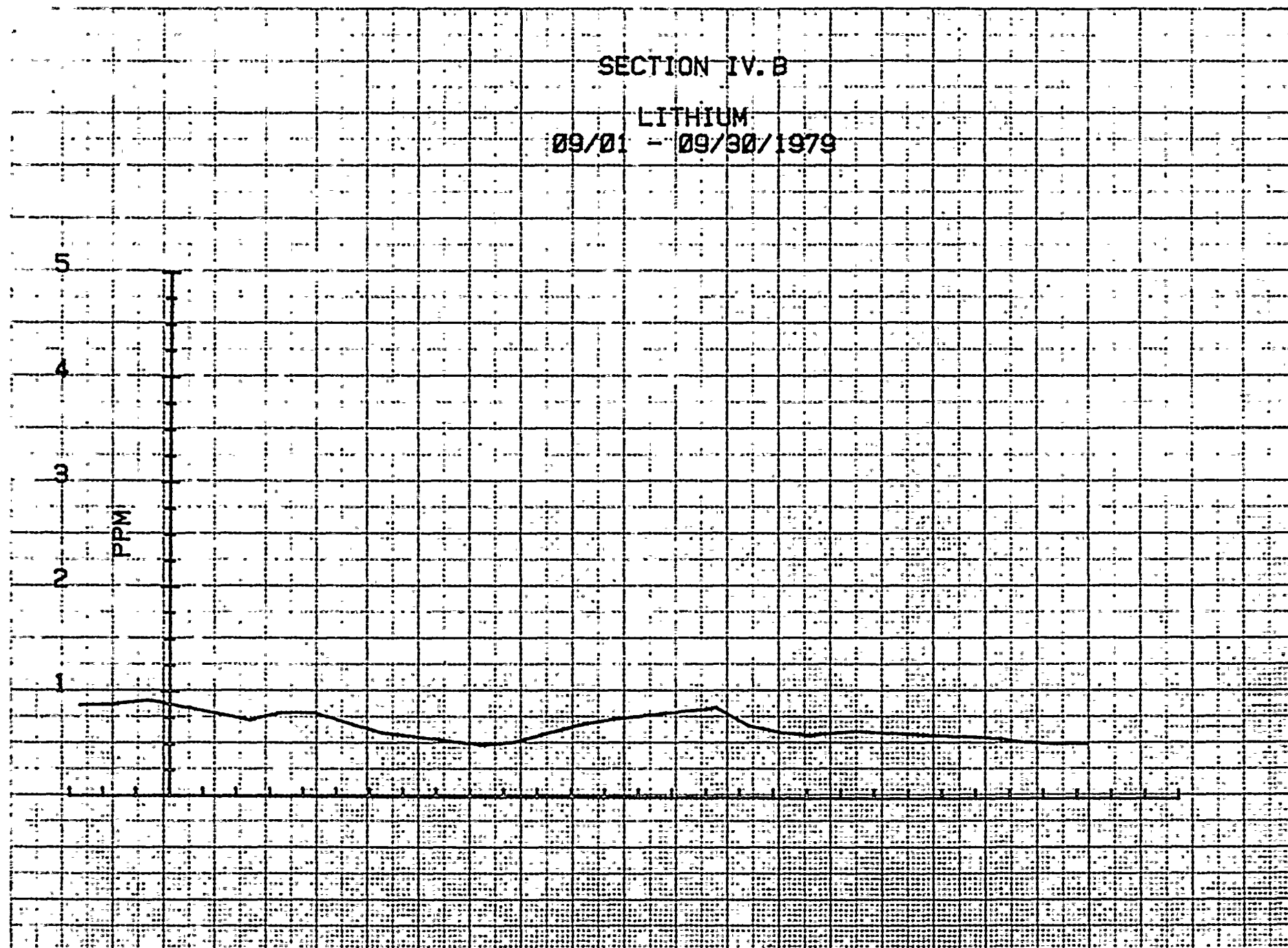




FIGURE B.19

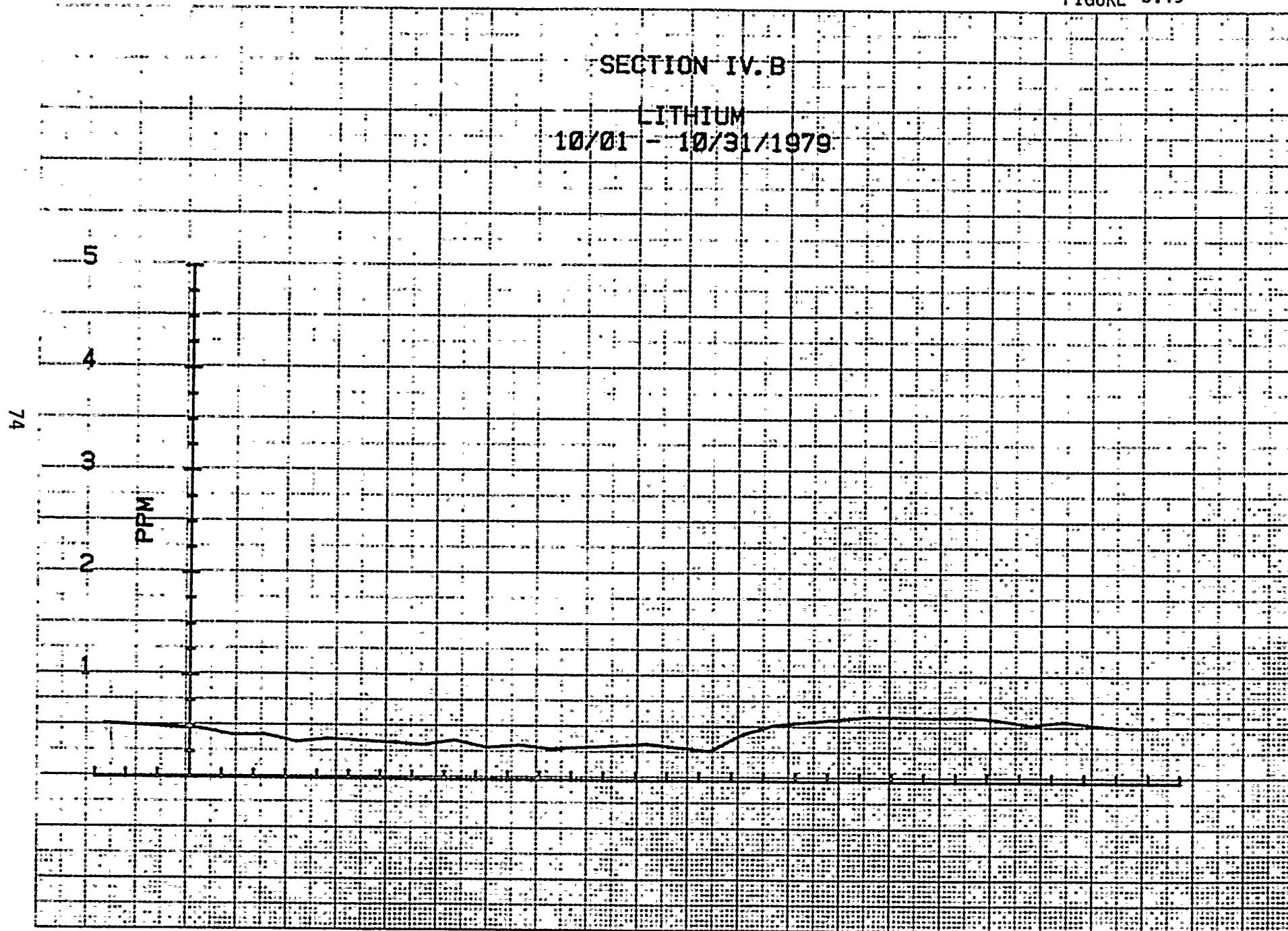




FIGURE B. 20

SECTION IV. B
LITHIUM
11/01 - 11/30/1979

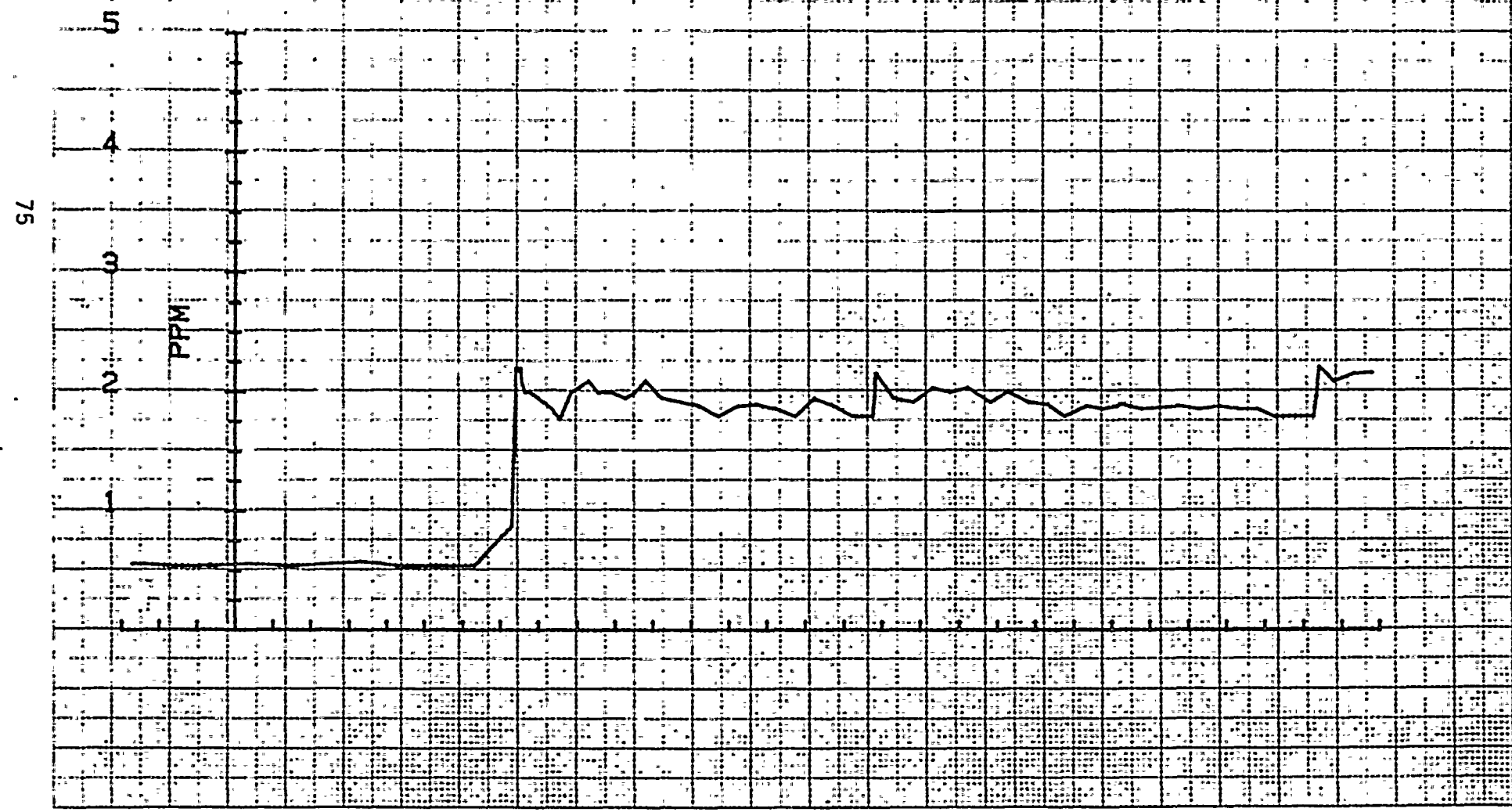
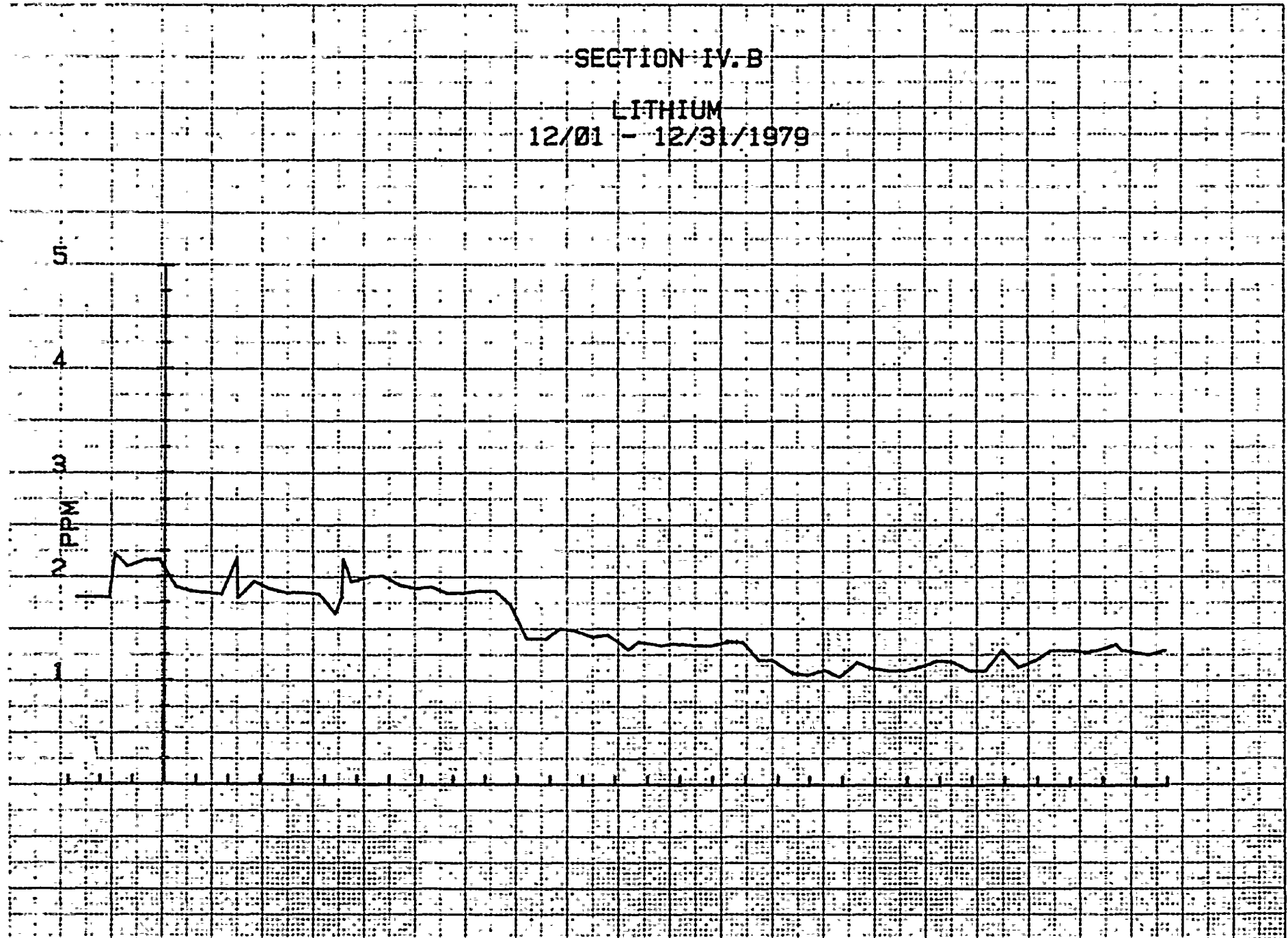


FIGURE B.21

SECTION IV.B
LITHIUM
12/01 - 12/31/1979

76



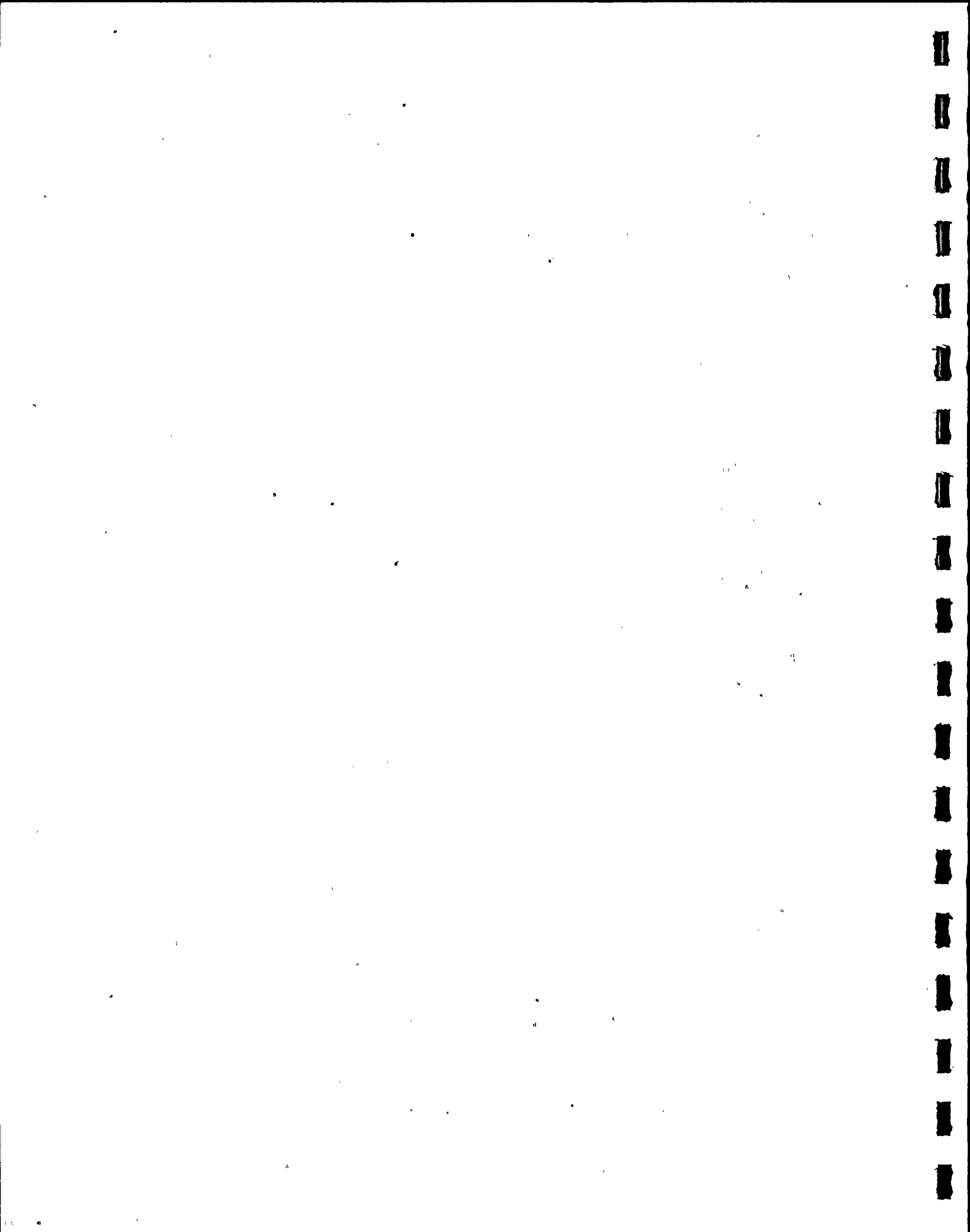


FIGURE B.22

SECTION IV-B

LITHIUM

01/01 - 01/31/1980

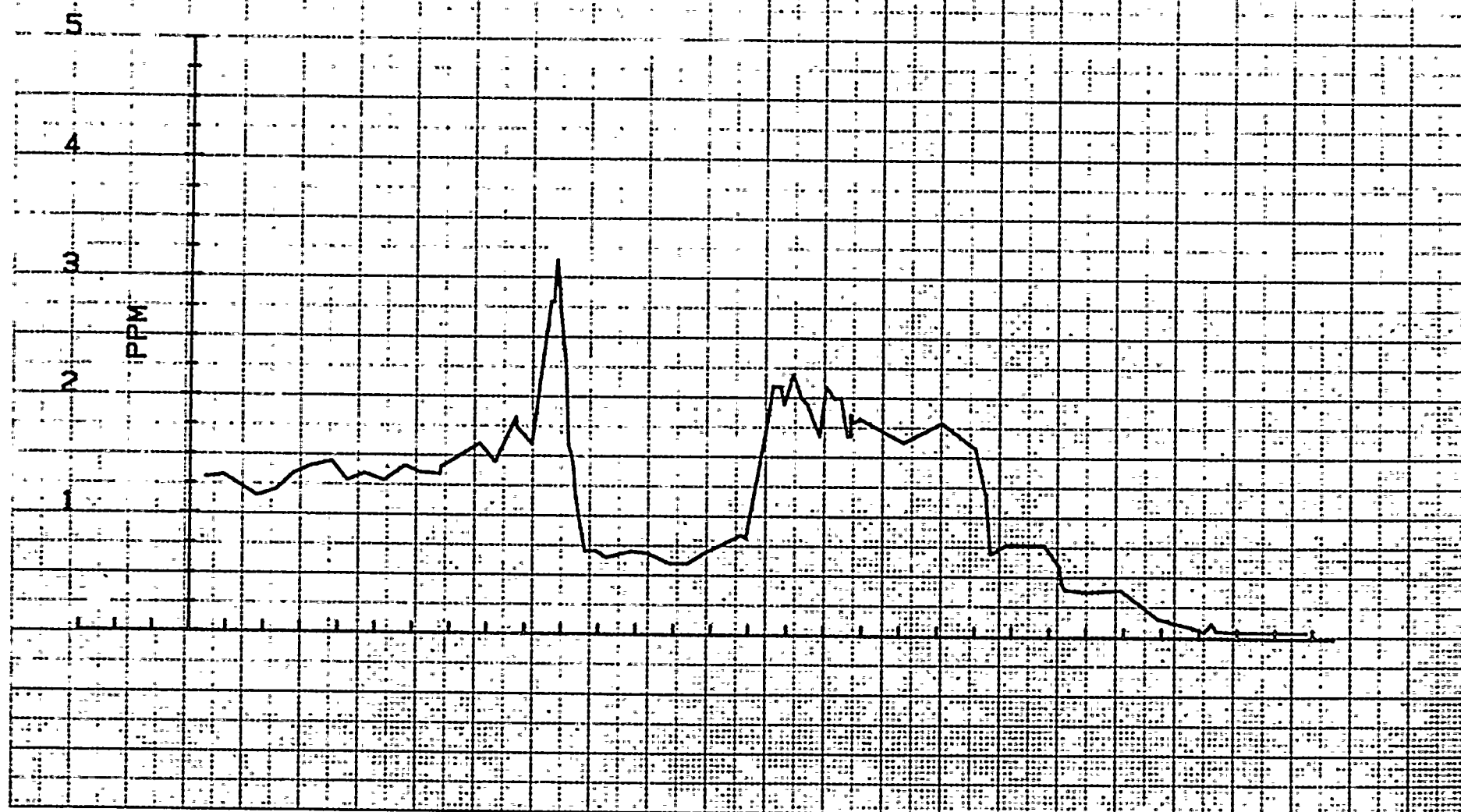




FIGURE B.23

SECTION IV. B

LITHIUM
02/01 - 02/29/1980

78

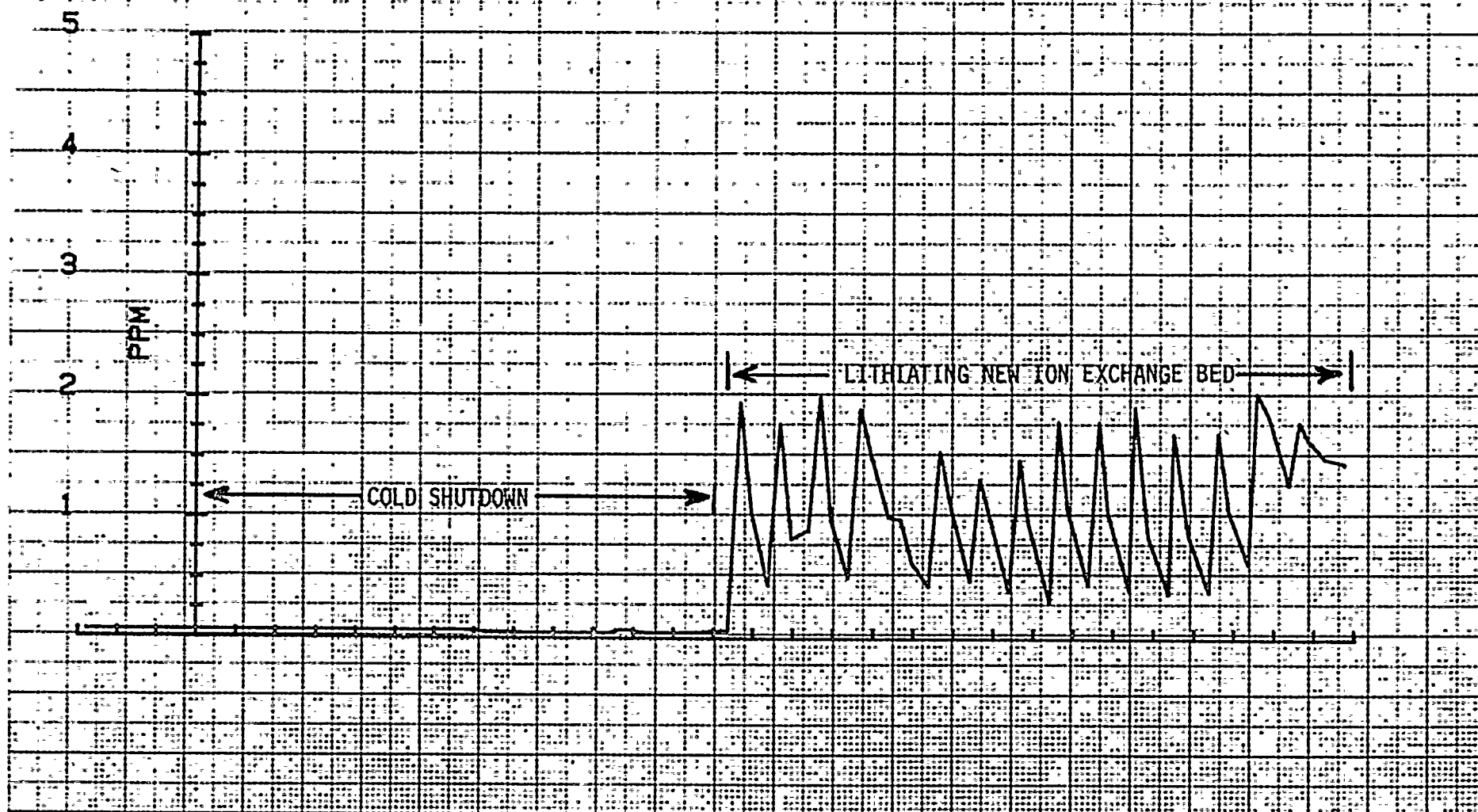




FIGURE B.24

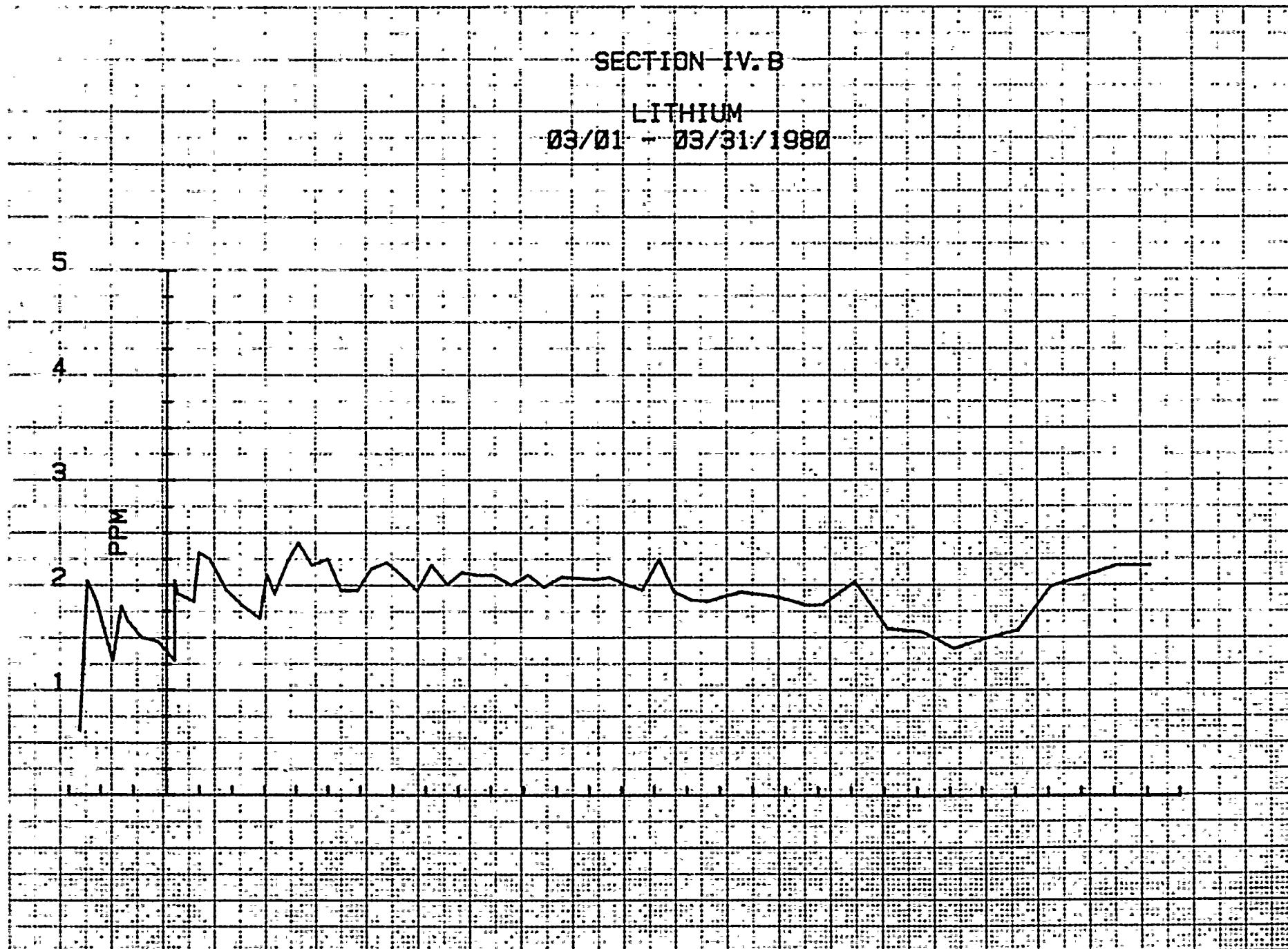
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SECTION IV.B

LITHIUM

03/01 - 03/31/1980

ppm

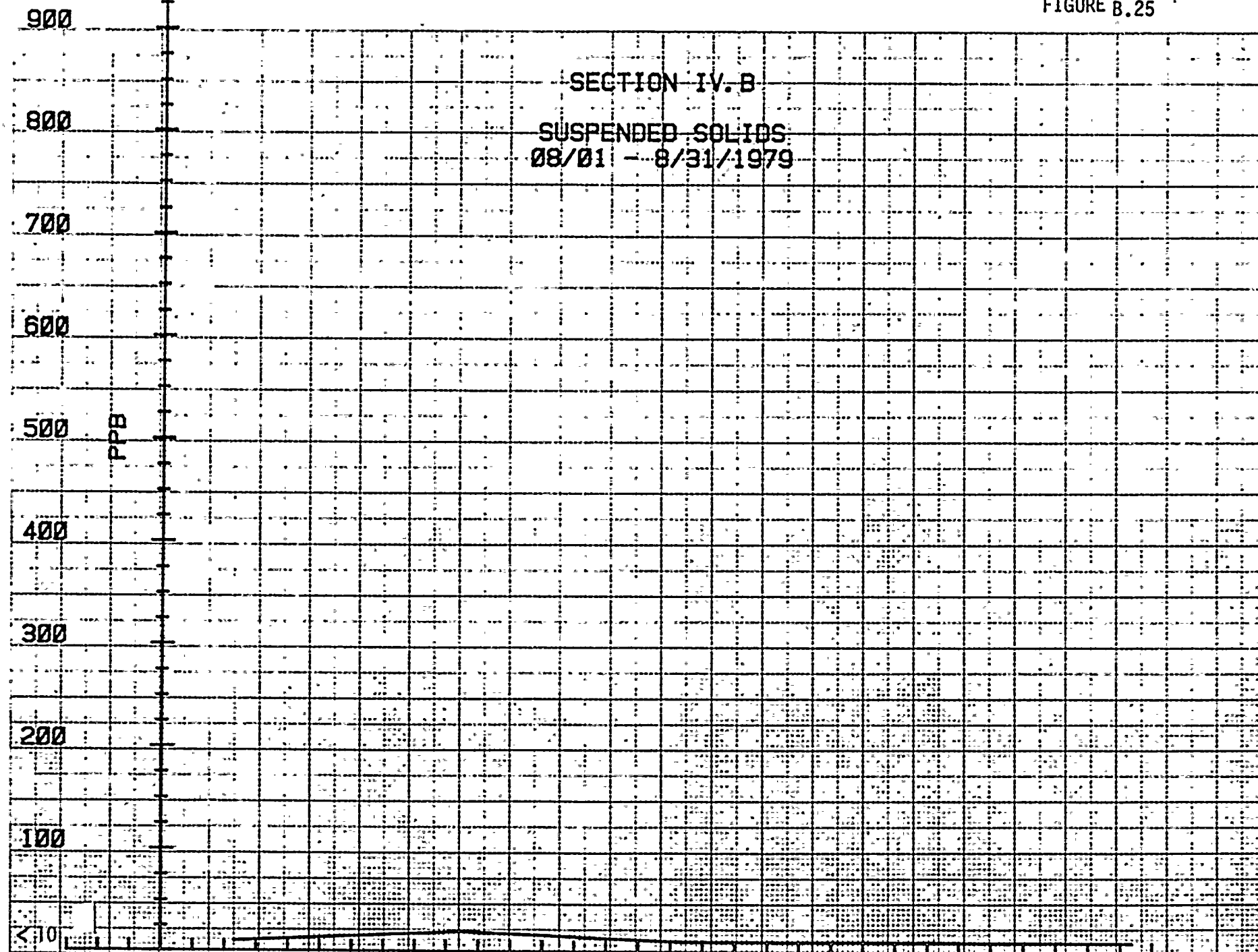


d. Suspended Solids (Figures B.25-32)

Figures B.25 through B.32 present the concentrations of suspended solids (s/s) found in the reactor coolant during the months of August 1979 through March 1980. The data indicates that for the period 08/01/79 to 11/11/79 (Figures B.25, B.26, B.27 and B.28) the levels were well within the CE and site specific guidelines of a 500 ppb maximum for normal operation. Values obtained were generally less than 25 ppb. On 11/08/78 the sampling frequency was increased from weekly to daily. Except for spikes attributable to plant power transients, suspended solids remained low (average ~50 ppb) until early December (Figure B.29). At this time, levels increased and became erratic, ranging from 100 to 500 ppb. These increases were attributed to the spalling of crud off the core, apparently as a result of chemistry actions taken in early November. Core dp began to rise during the second week of December, possibly as a consequence of an increase in the roughness of the remaining core crud deposits due to spalling. Concurrently, the reactivity and power distribution anomalies appeared to recede, as discussed on Section III. The very large spike of 1/10/80 followed an inadvertent over-addition of hydrazine, and is discussed in Section IV.B.2.b. The addition of hydrogen peroxide to the RCS during cold shutdown on 1/27 produced a large increase on suspended solids, as expected. The hydrogen peroxide treatment is further discussed in Section IV.B.2.d.

FIGURE B.25

18



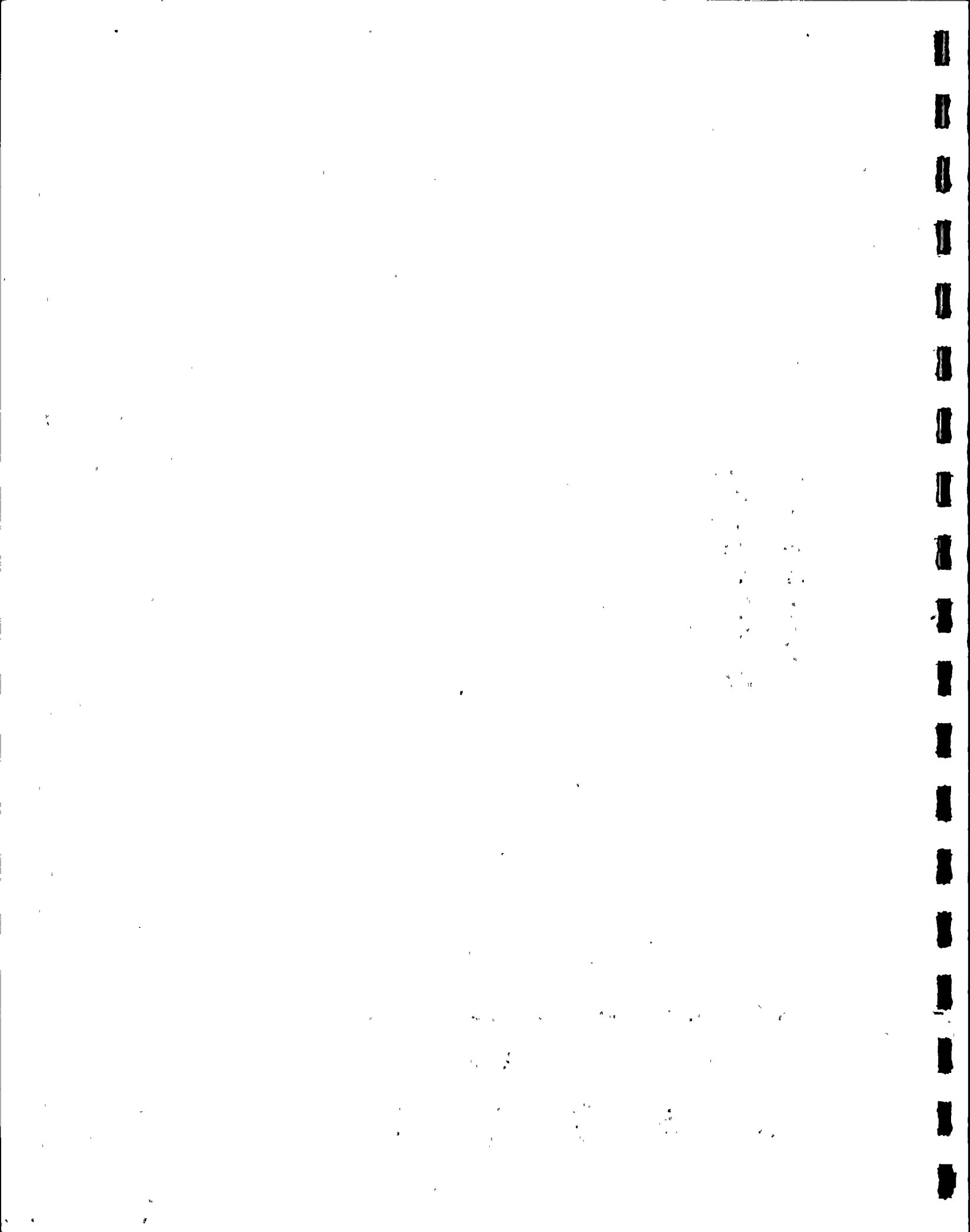


FIGURE B.26

SECTION IV.B
SUSPENDED SOLIDS
09/01 - 09/30/1979

900

800

700

600

500

400

300

200

100

<10

PPB

82

8-0

5 1/2" x 11" (140mm x 280mm) 1/16" (1.6mm) thick

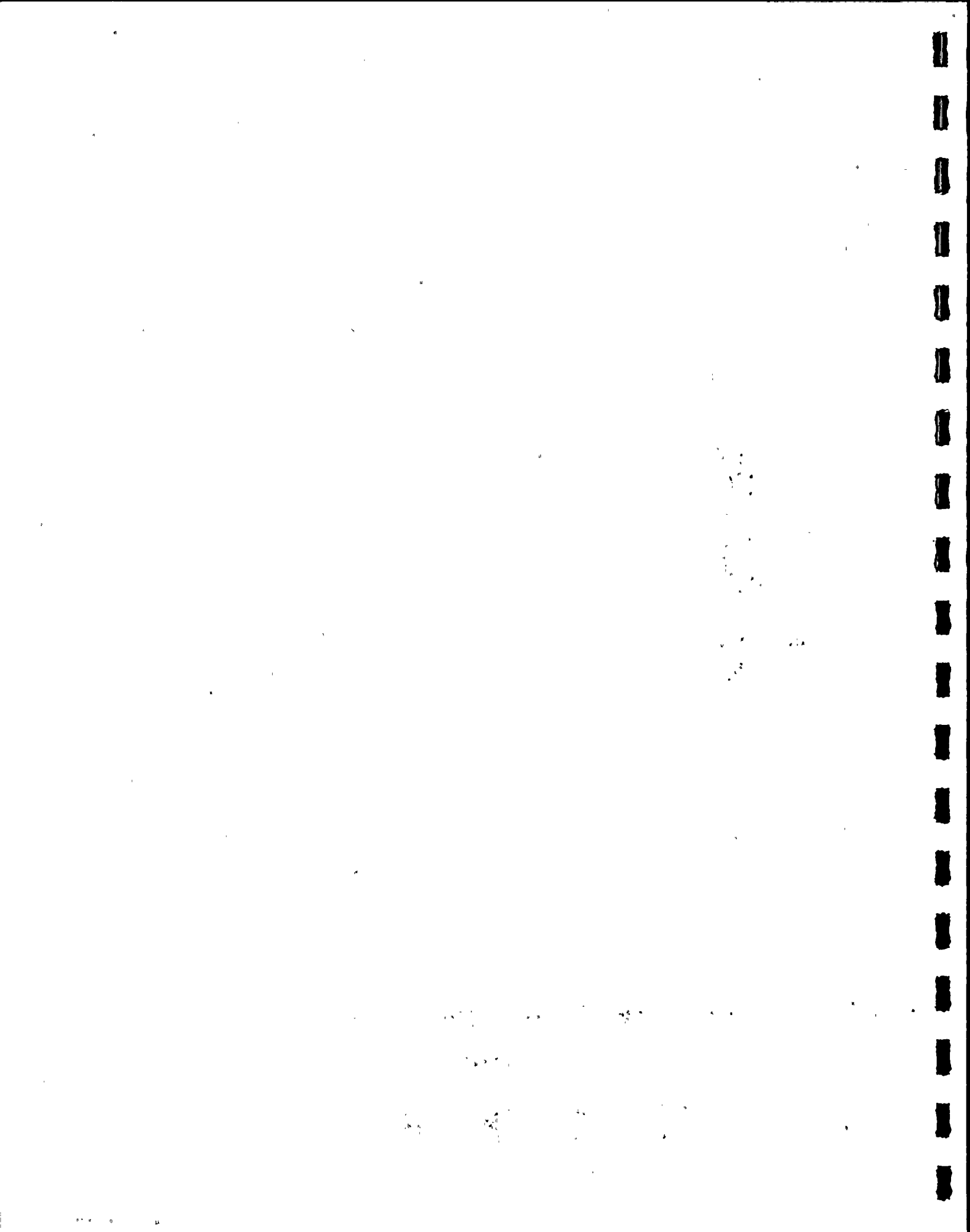


FIGURE B.27

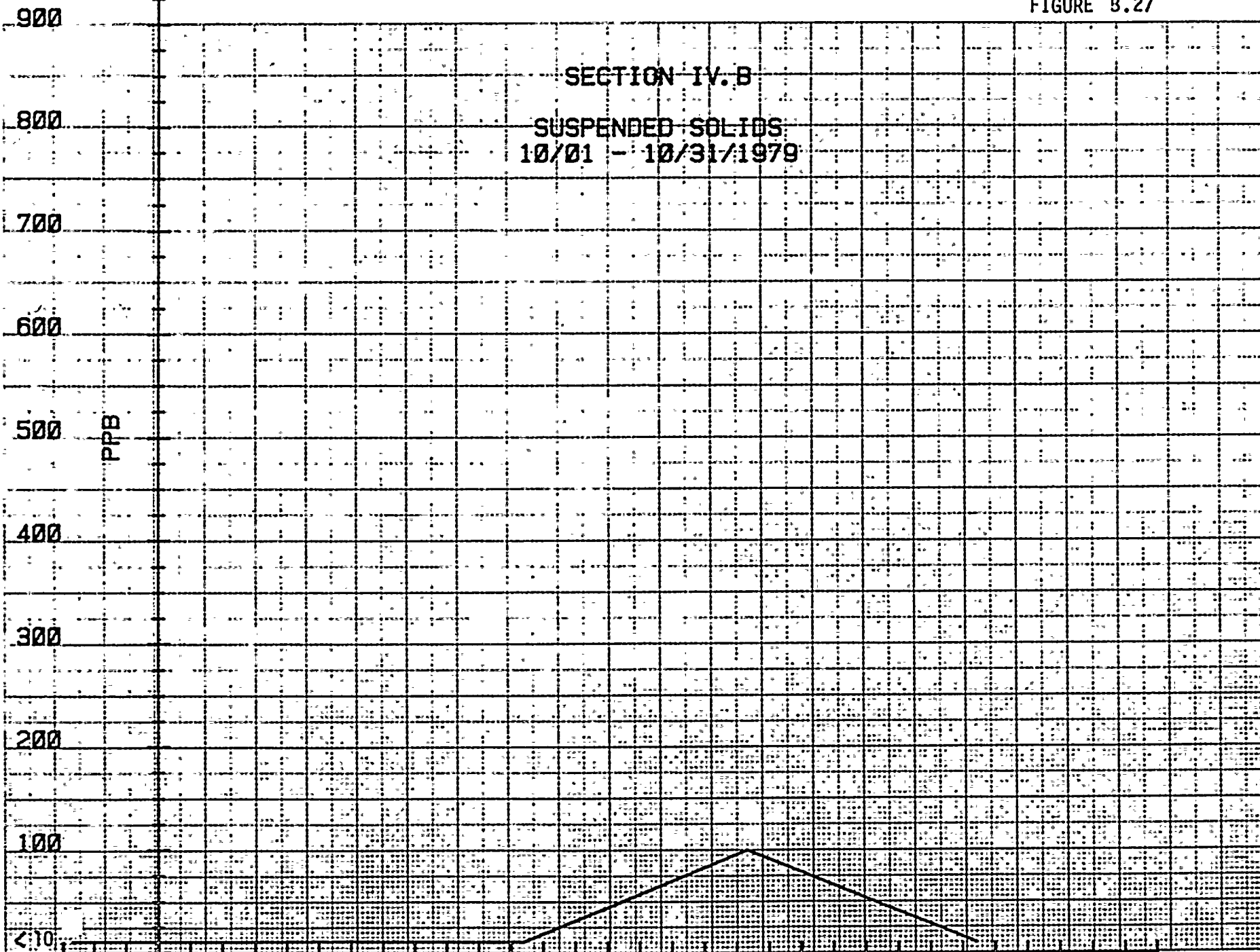


FIGURE B.28

84

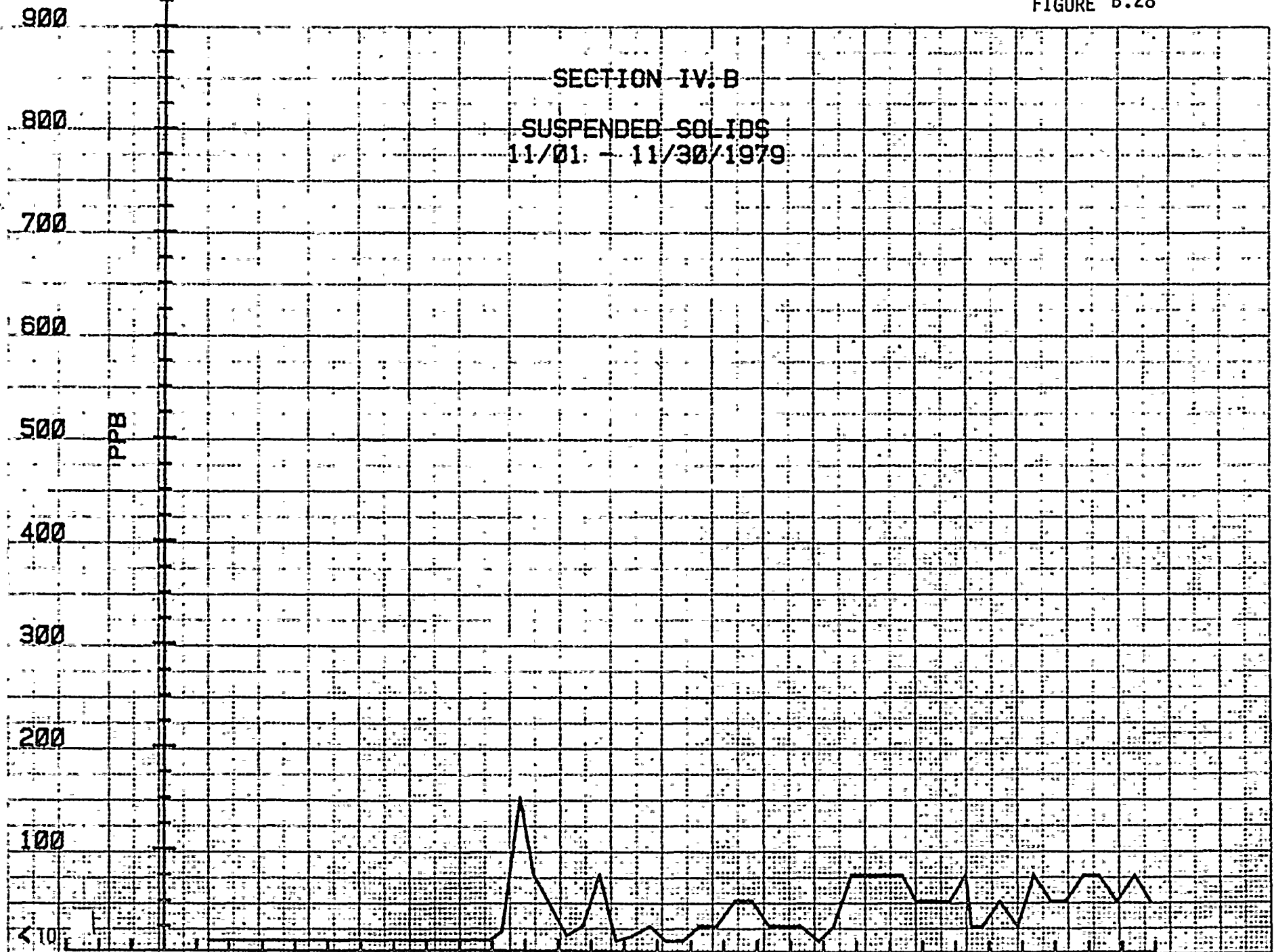
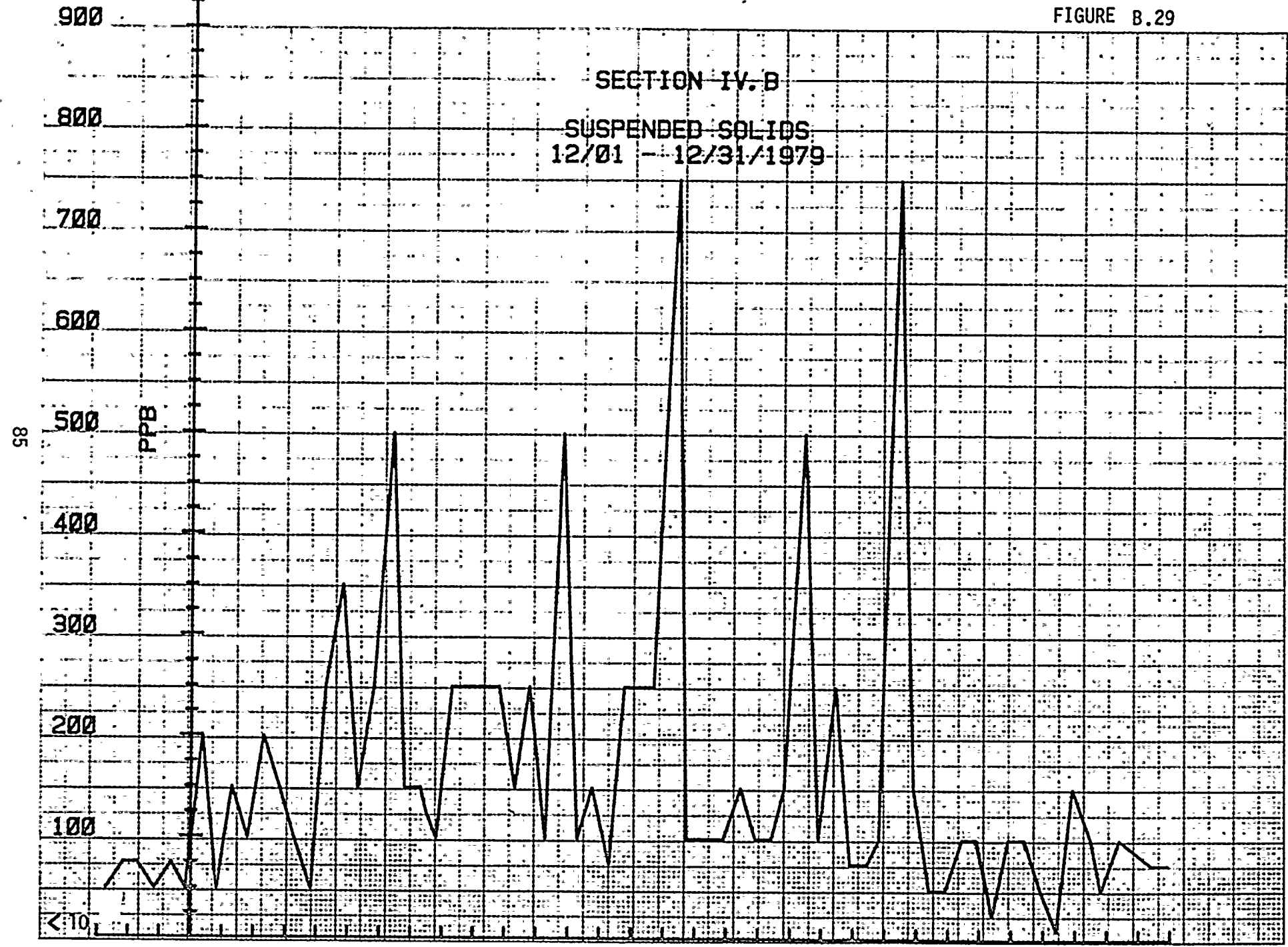


FIGURE B.29



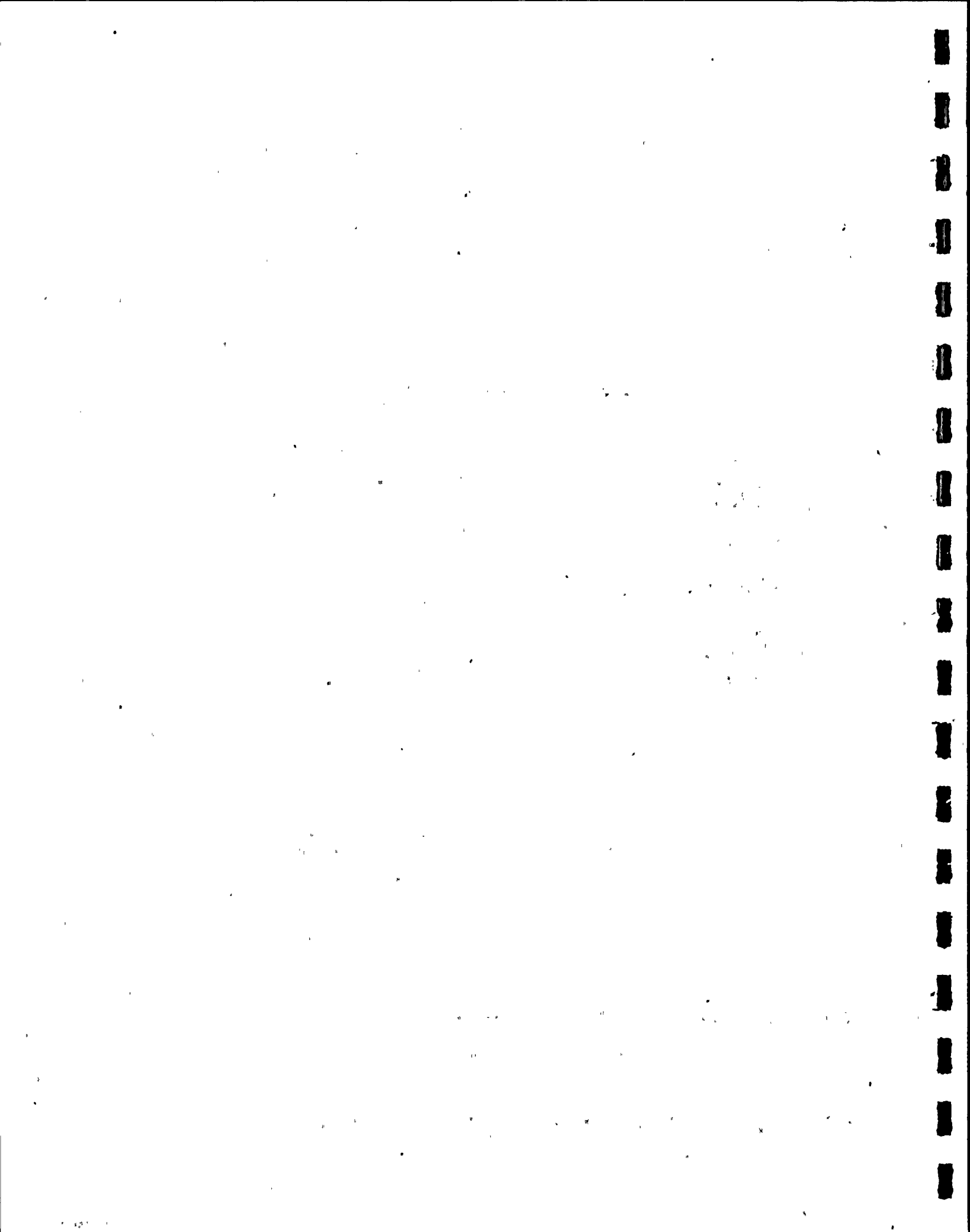


FIGURE B.30

SECTION IV.B
SUSPENDED SOLIDS
01/01 - 01/31/1980

98

PPB

900
800
700
600
500
400
300
200
100
0

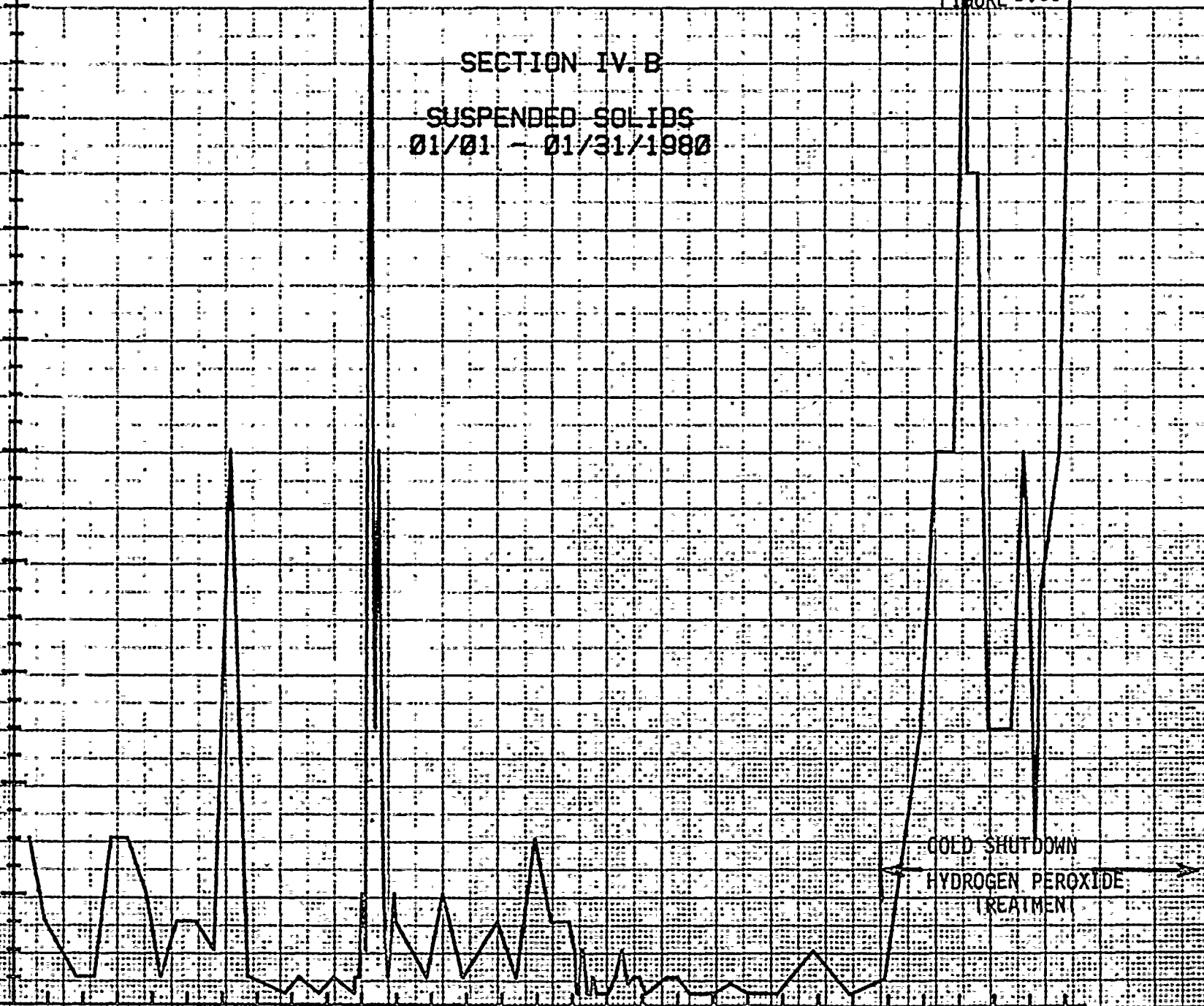


FIGURE B.31

87

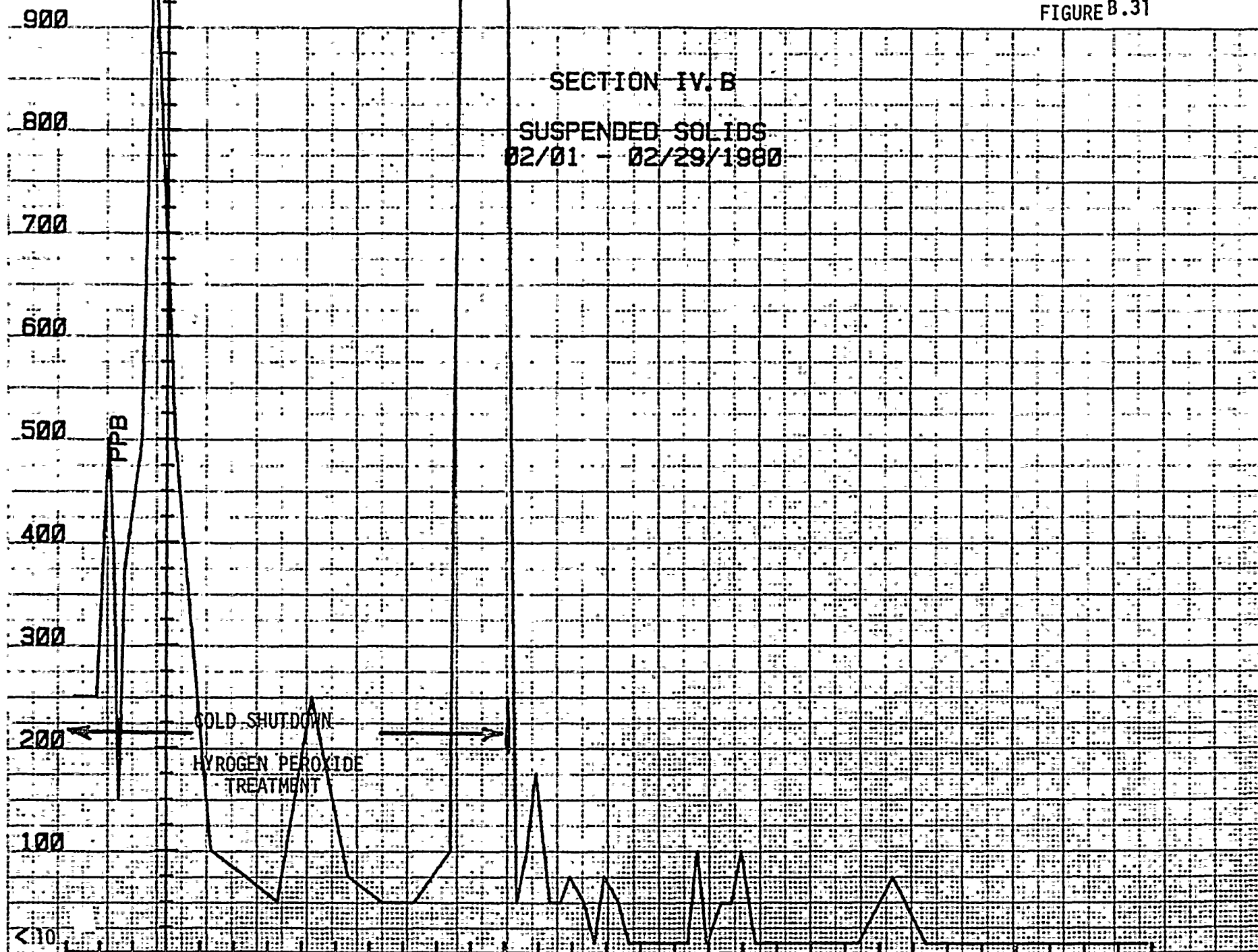


FIGURE B.32

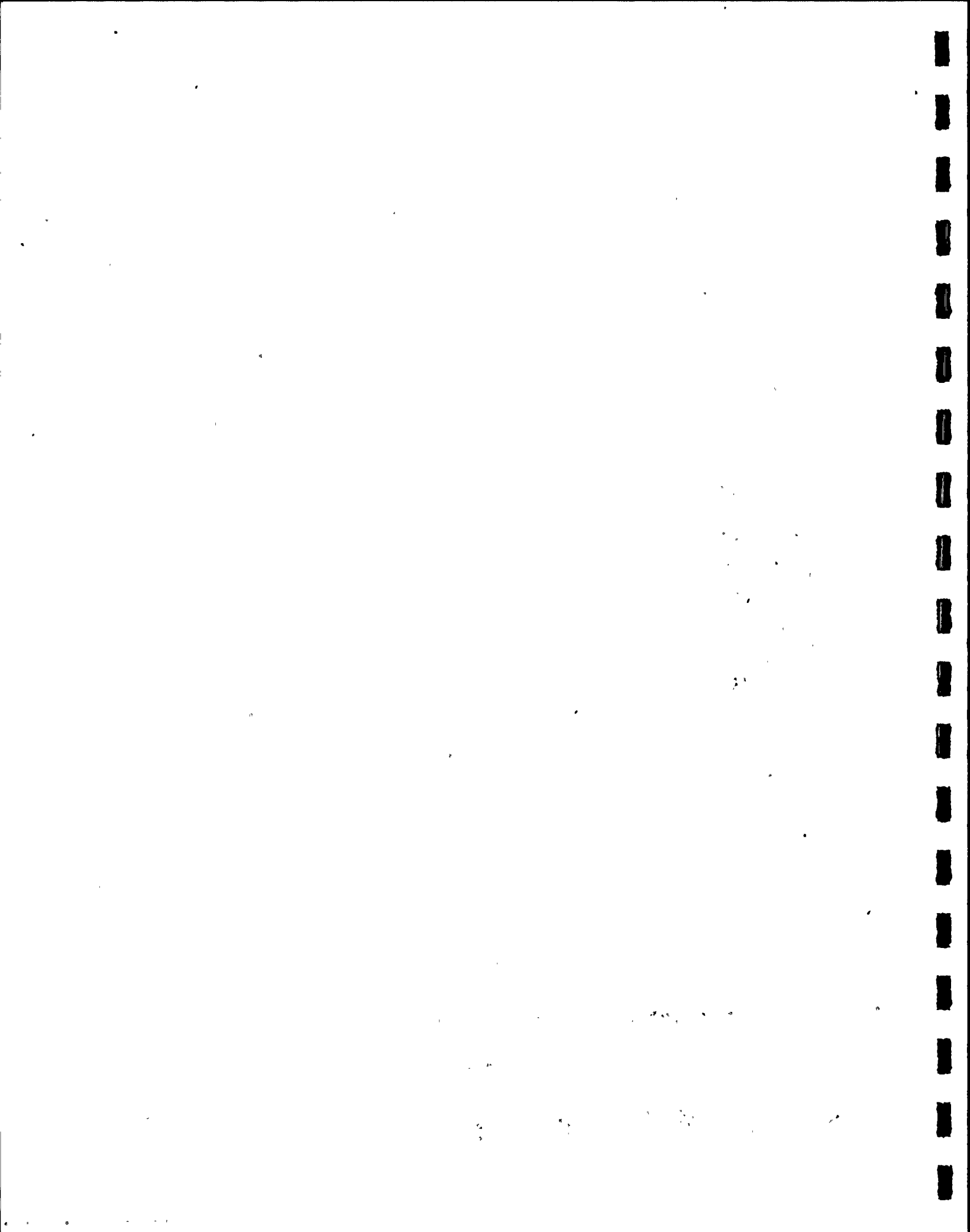
SECTION IV.B
SUSPENDED SOLIDS
03/01 - 03/31/1980

900
800
700
600
500
400
300
200
100
<10

PPB

88





e. Hydrogen (Figures B.33-40)

Examination of Figures B.33 through B.40 illustrate the following points:

- (1) During the period 08/01/79 to 11/1/79 hydrogen in the RCS was controlled within the guidelines of both CE and site specific specifications (Reference Table IV.A.1). All samples obtained during this period were in the range of 10-50 cc/kg. Note that the analysis method for RCS hydrogen is performed utilizing VCT vapor phase hydrogen concentration.
- (2) Subsequently the hydrogen concentration in the RCS was increased to a nominal range of 50-80 cc/kg. This modification to the chemistry program was prompted by a CE recommendation to increase RCS hydrogen inventory.

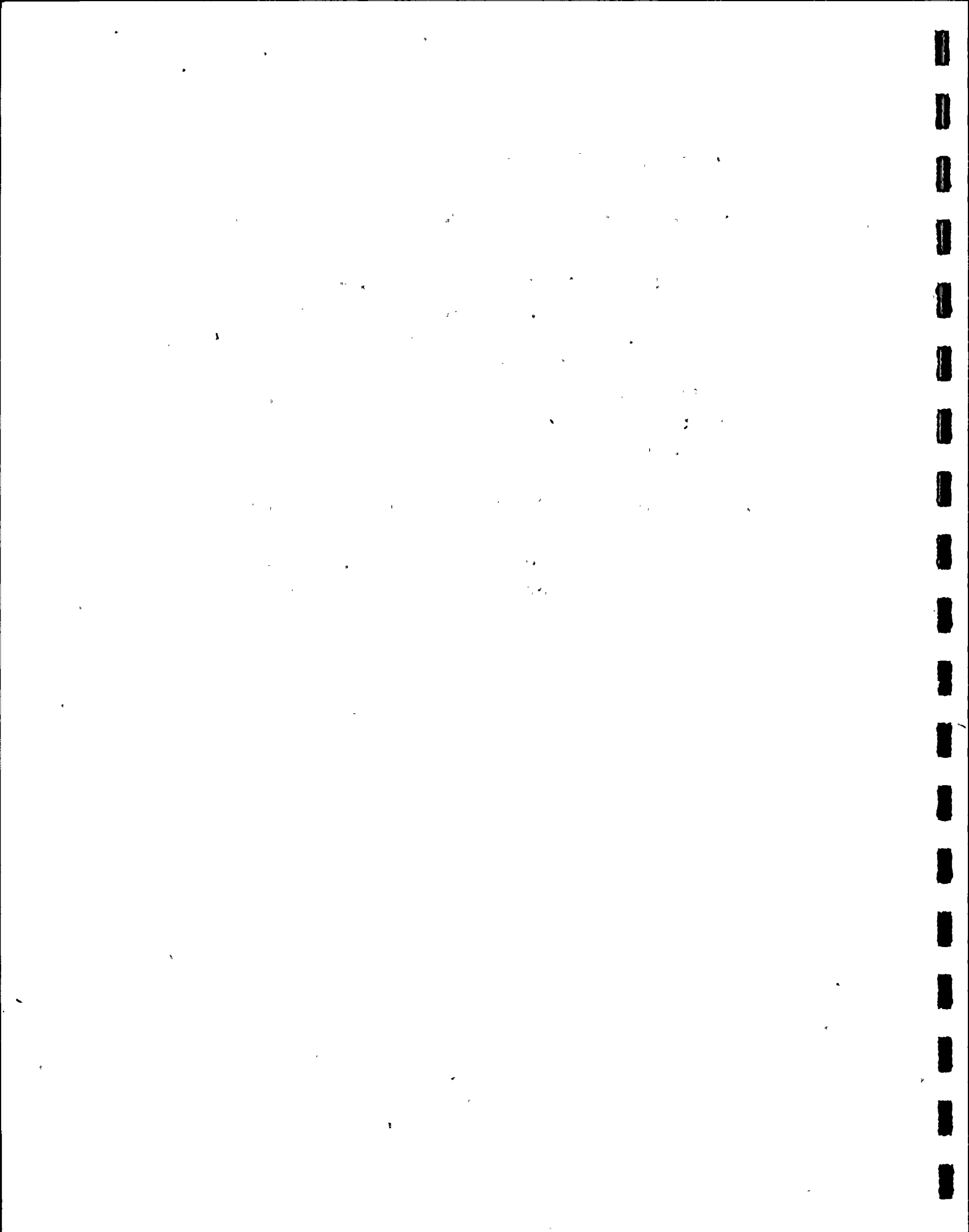


FIGURE B.33

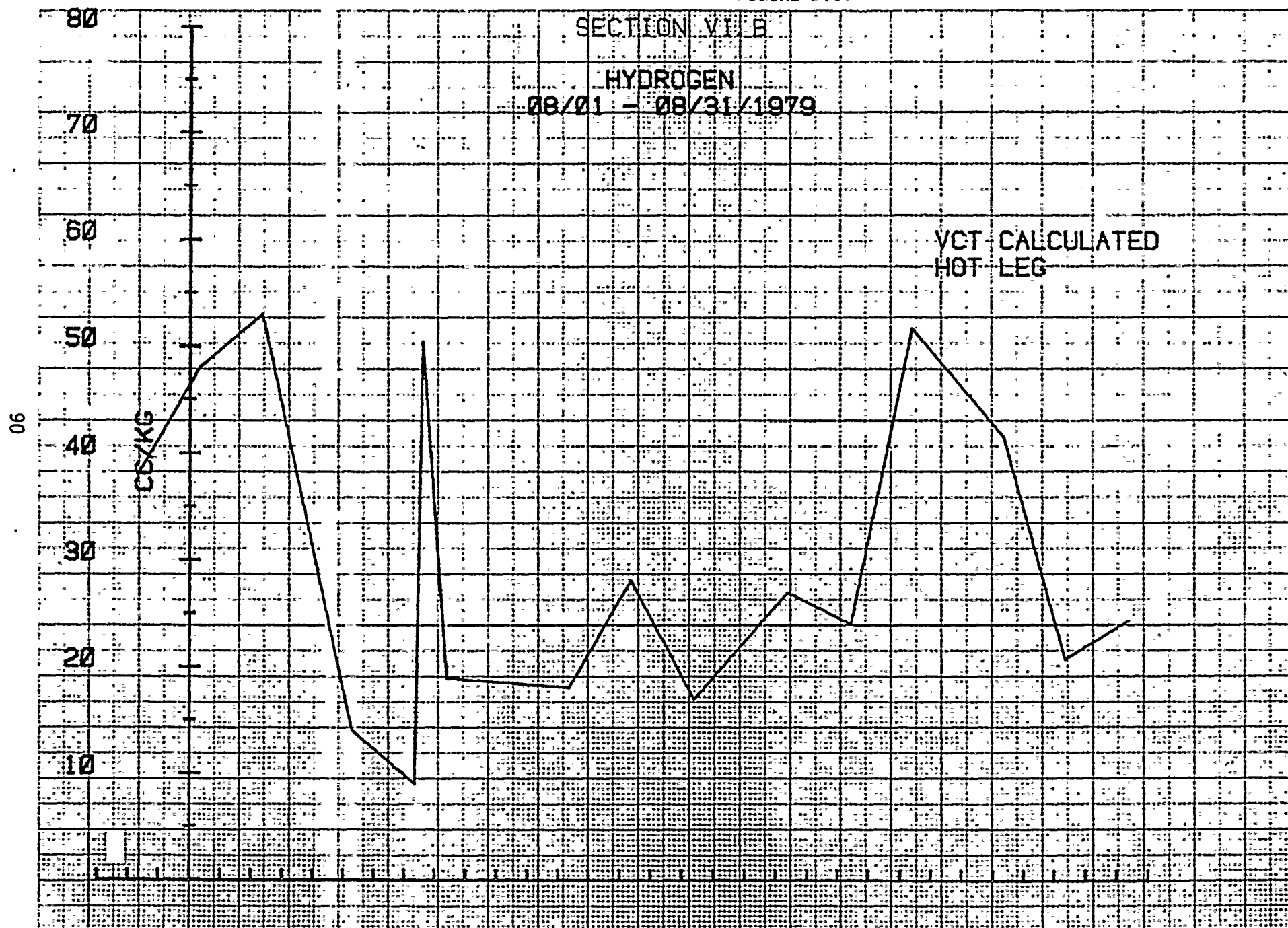


FIGURE B.34

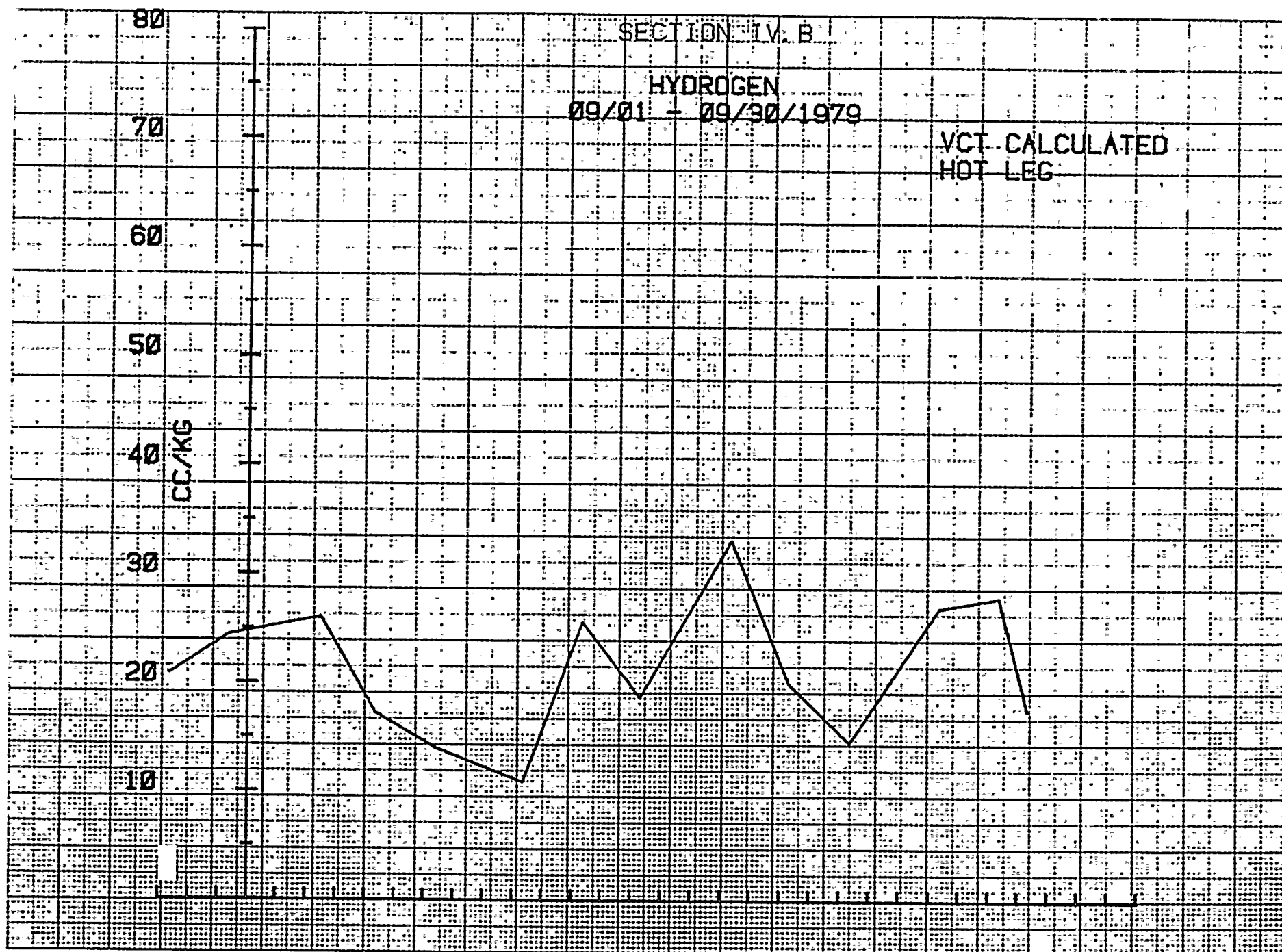
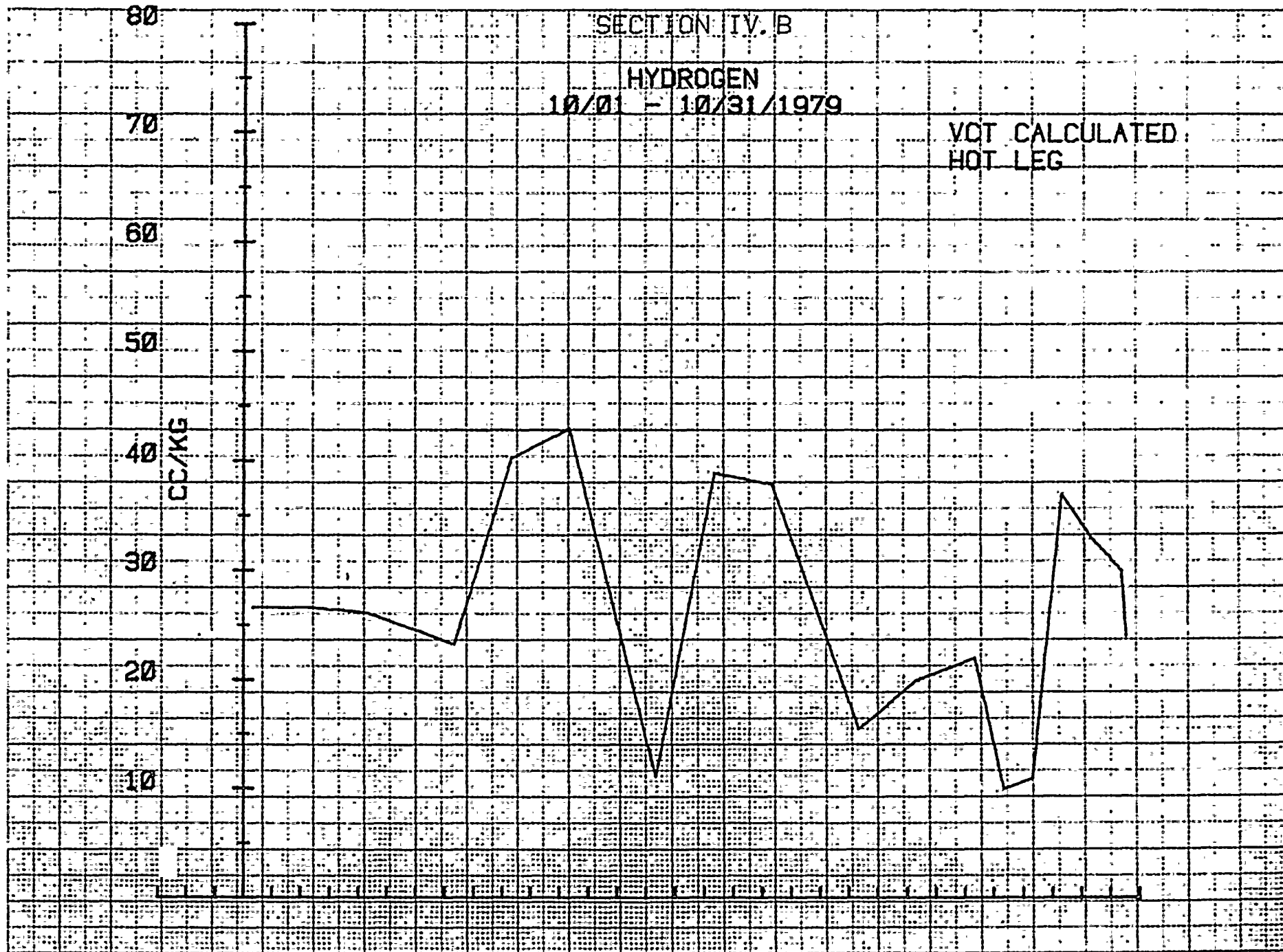


FIGURE B.35



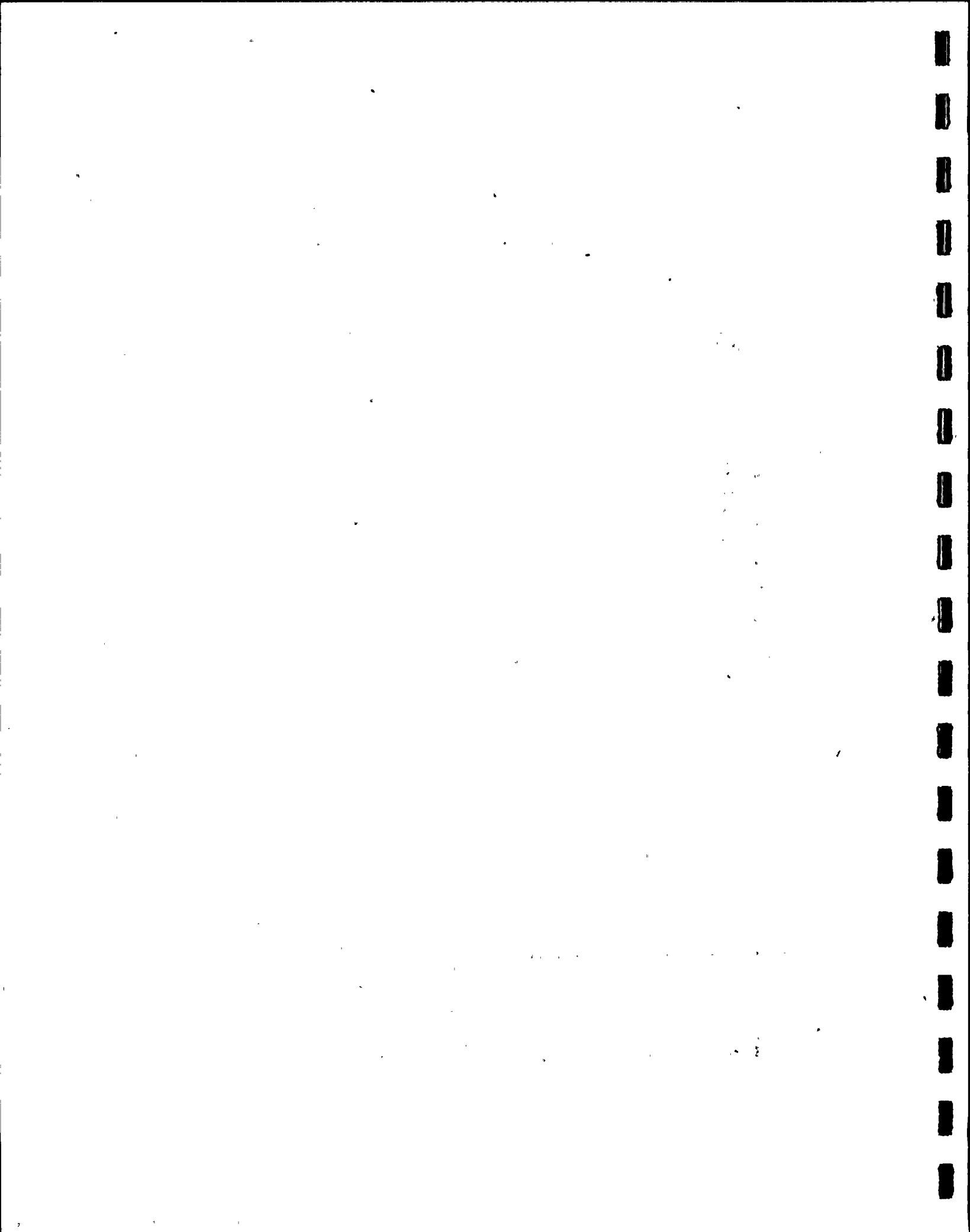
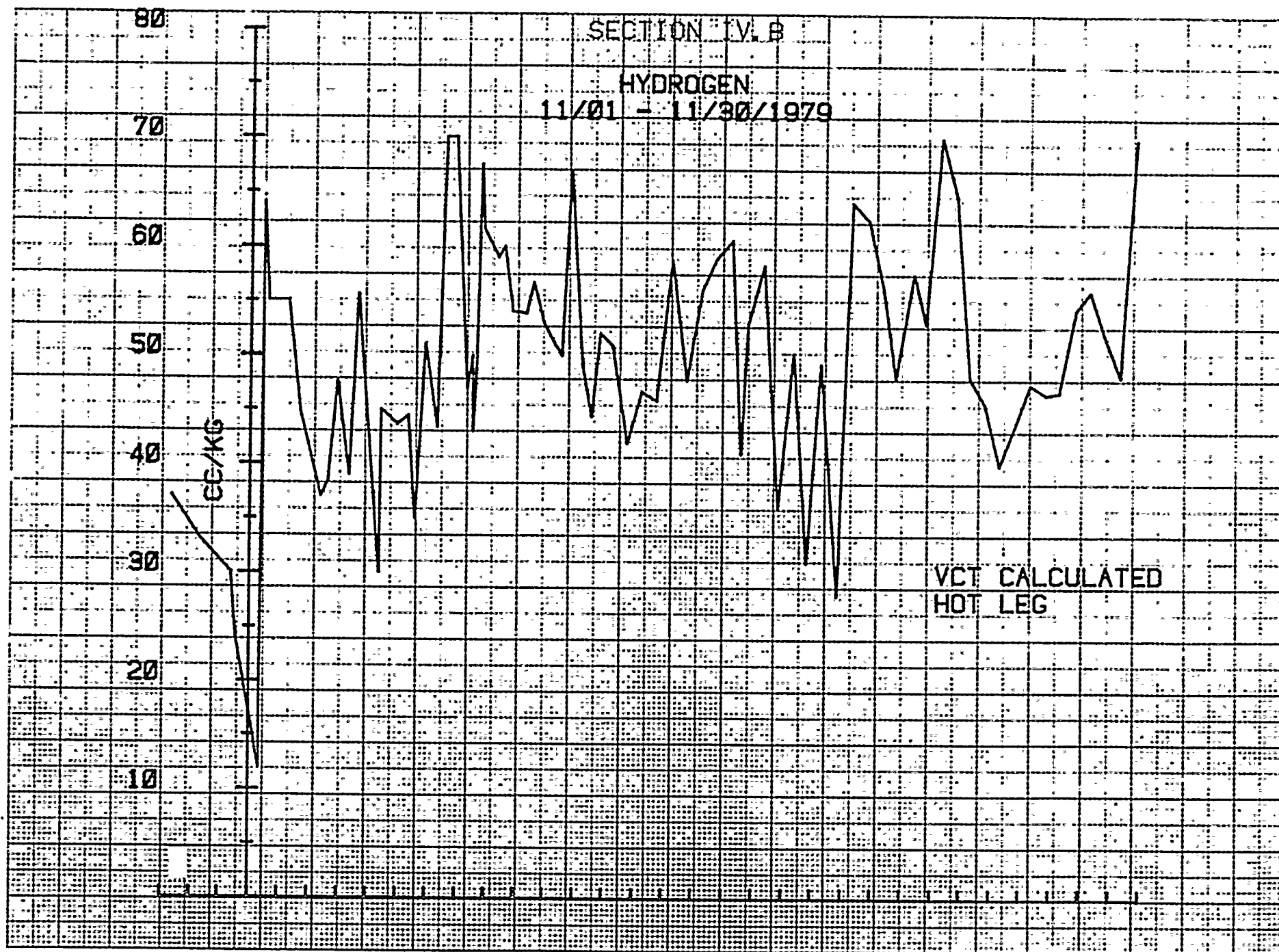


FIGURE B.36



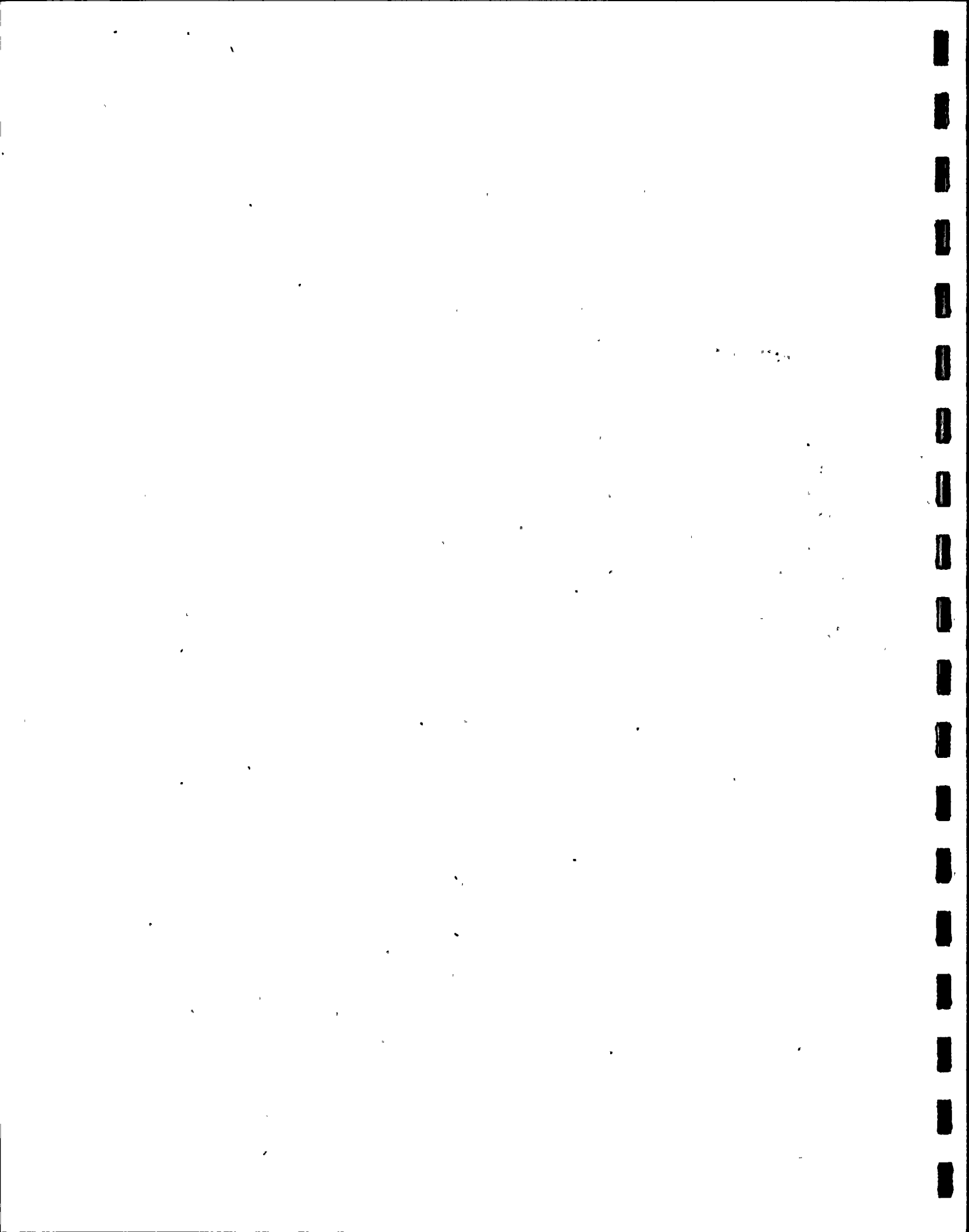


FIGURE B.37

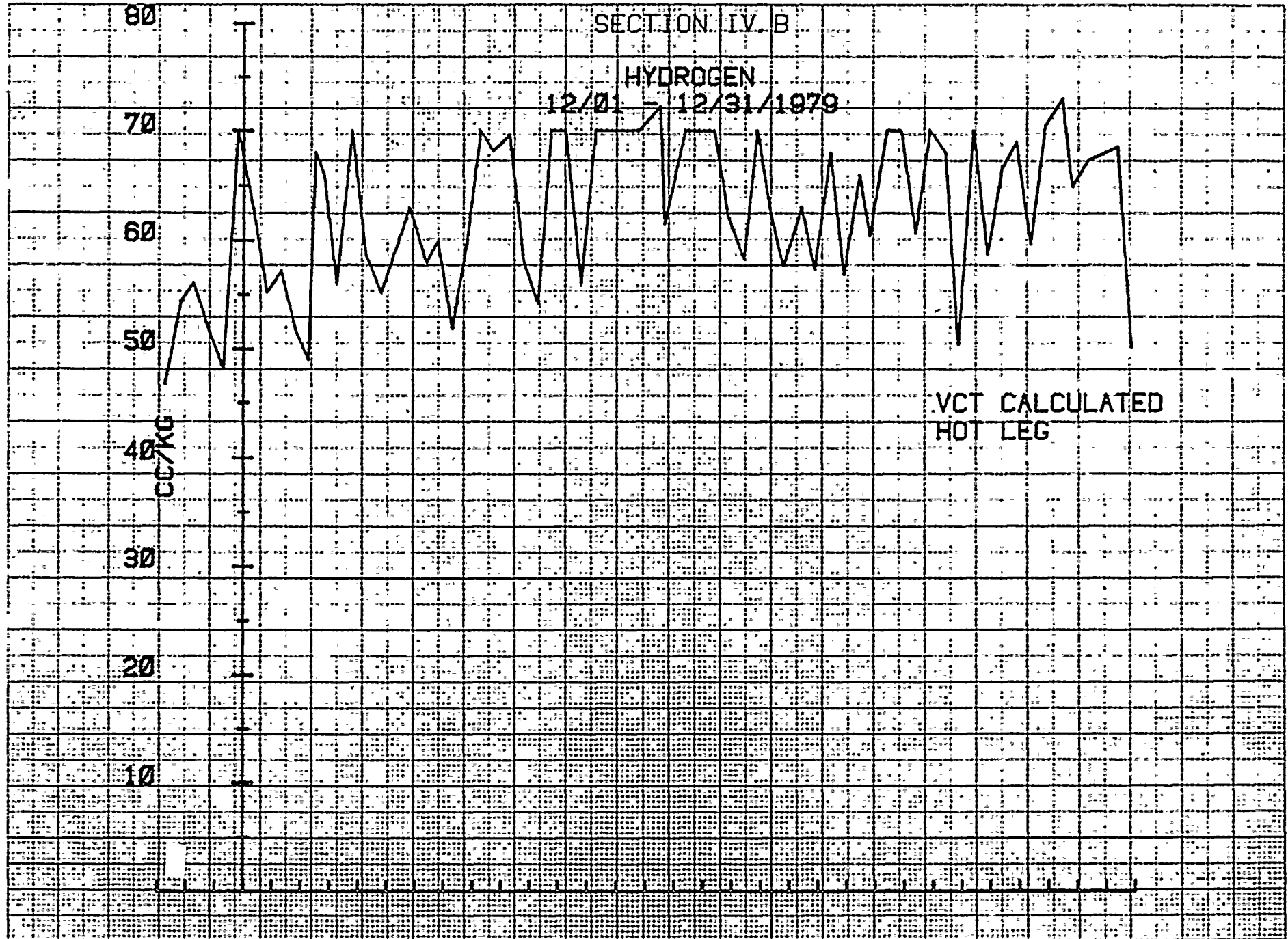


FIGURE B.38

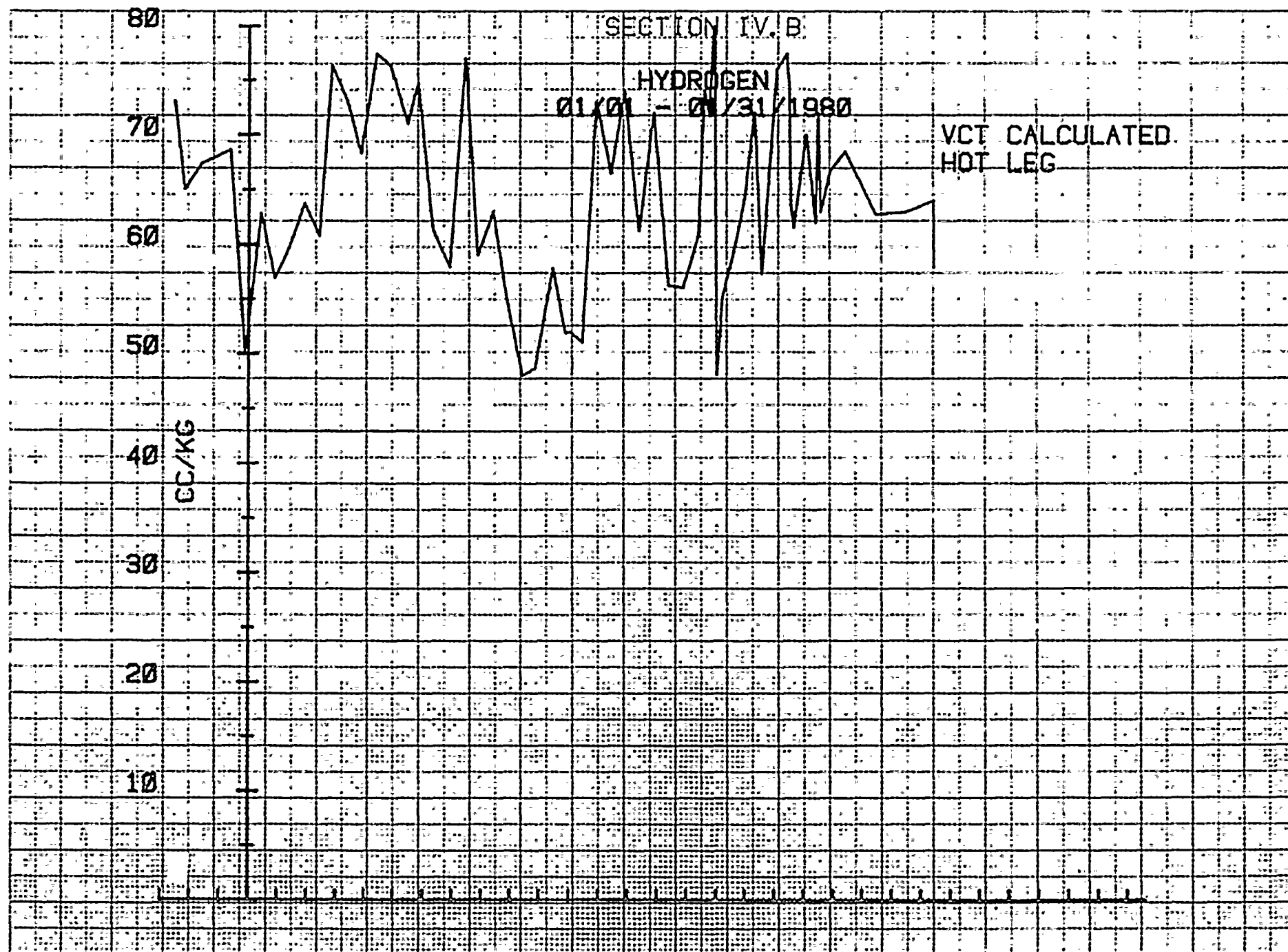
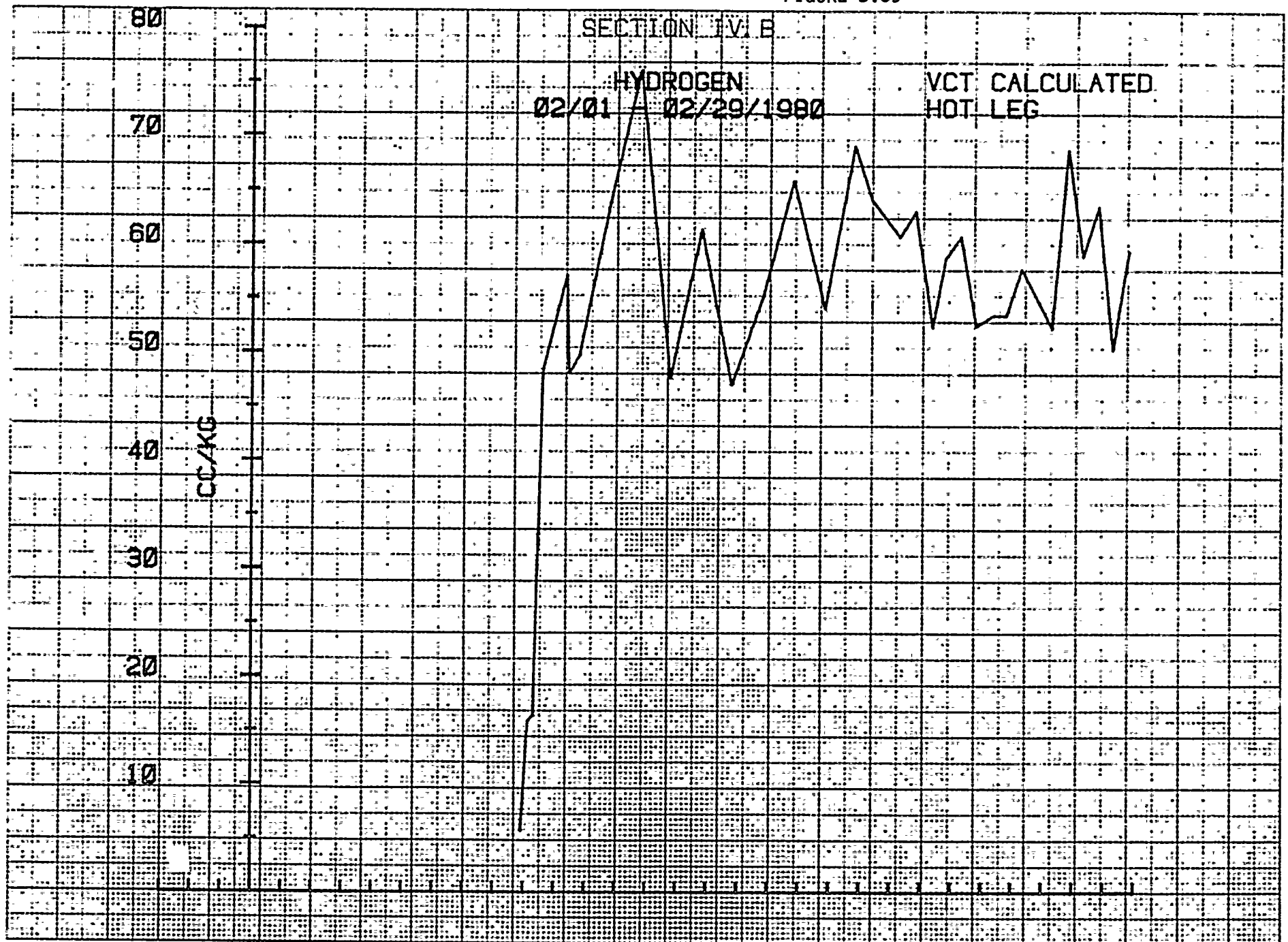


FIGURE B.39



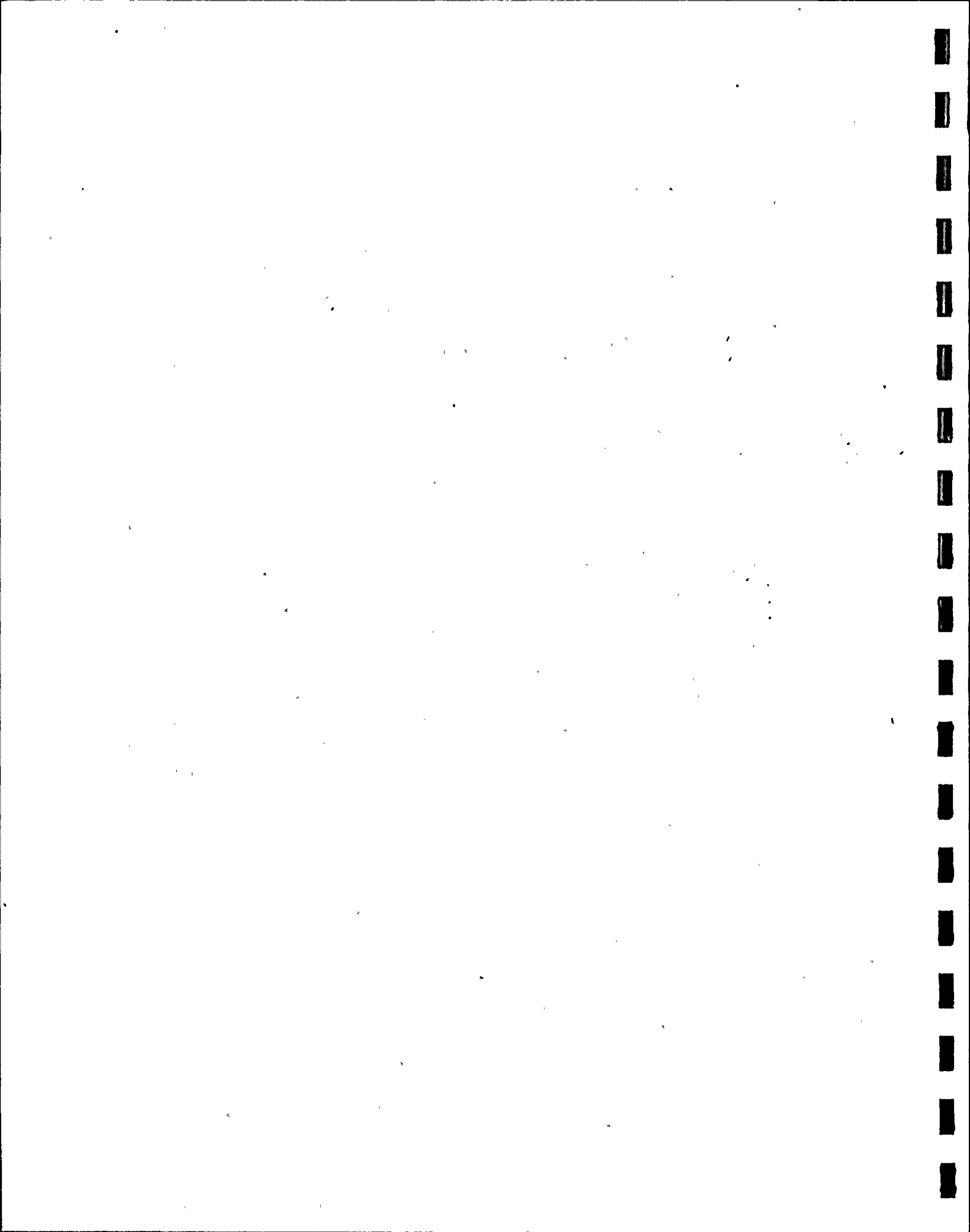
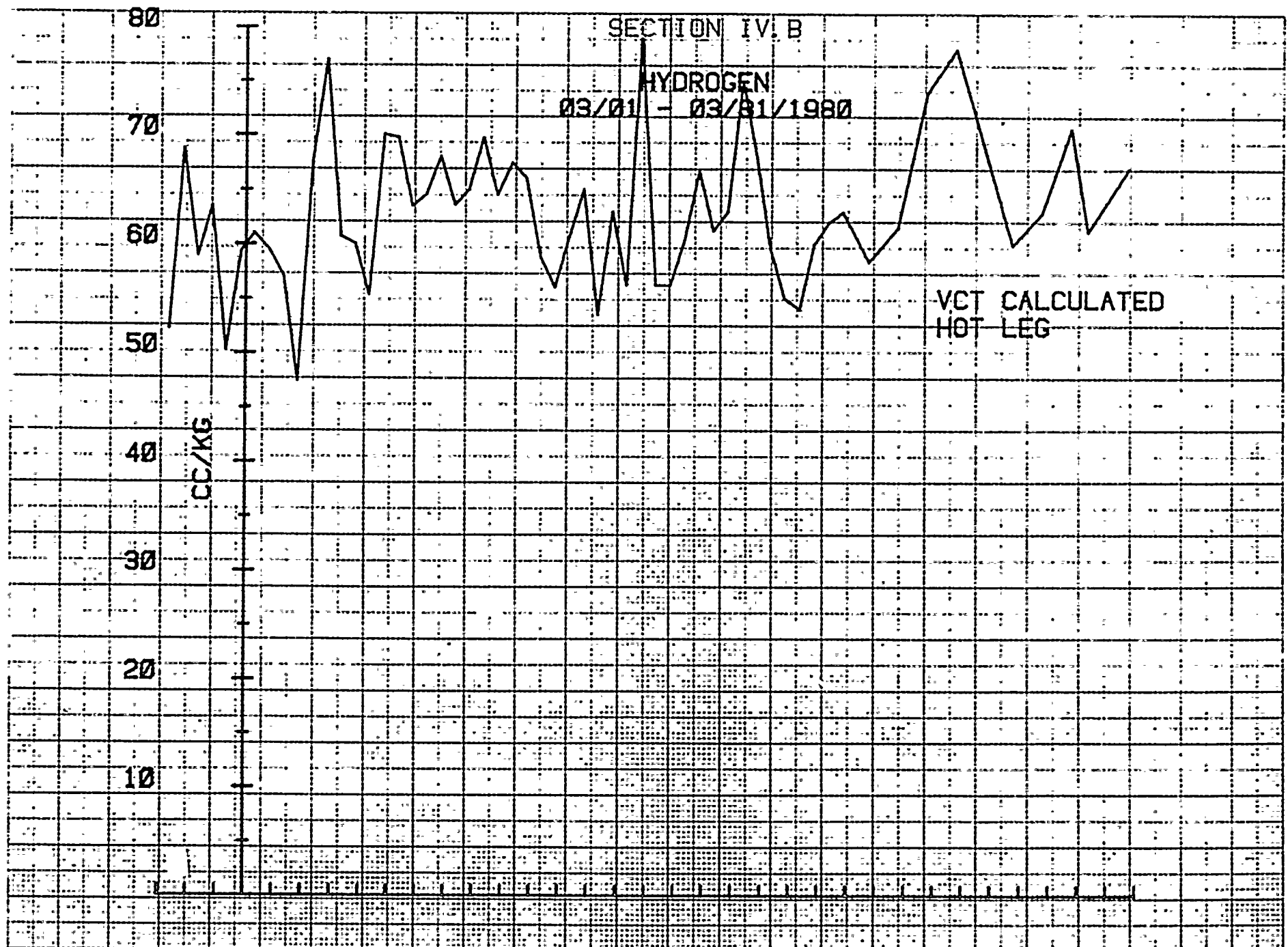


FIGURE B.40



f. Oxygen (Figures B.41-48)

A detailed study of Figures B.41 through B.48 generate the following points of interest:

- (1) RCS oxygen concentrations under normal operating conditions were at all times within the CE and site specific guidelines (Reference Table IV.A.1). A nominal value for oxygen data points was <10 ppb.
- (2) In early November 1979, plant staff routinely analyzed the oxygen concentration in the VCT (based upon a charging pump discharge sample point). Although not recommended by Reference 1 this action was prompted by a subsequent CE recommendation to investigate sources of oxygen ingress to the RCS. Nominal values for VCT oxygen were less than 100 ppb. However, on several occasions (i.e. December 20, 1979, 800 ppb) there were significant increases in oxygen values. Sources of oxygen ingress were determined to be via the resin transfer system and from partial aeration during storage of the normally deaerated makeup water. Oxygen ingress to the RCS is discussed in Section IV.B.2.c.
- (3) In late December hydrazine injection to the CVCS was established as a normal operation. The purpose for the hydrazine addition was to compensate for oxygen concentrations in the RCS makeup water due to air absorption in the demineralized water storage tank. Pursuant to a CE recommendation hydrazine was injected at a rate and concentration sufficient to establish an approximately 10:1 hydrazine to oxygen ratio. The ratio was later modified to 5:1 in response to subsequent CE recommendations. Further discussion of the hydrazine/oxygen concentration is contained in Section IV.B.2.b.

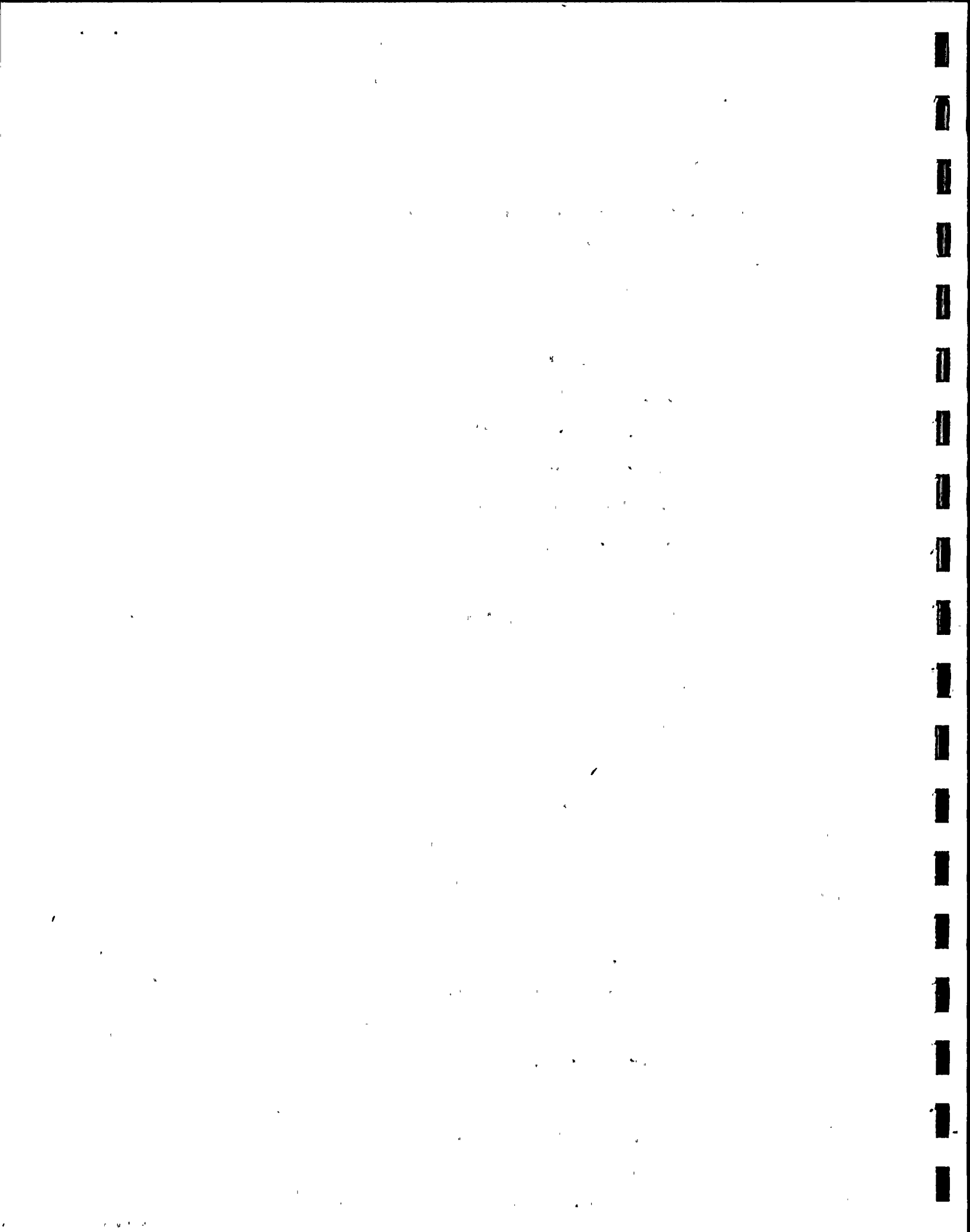
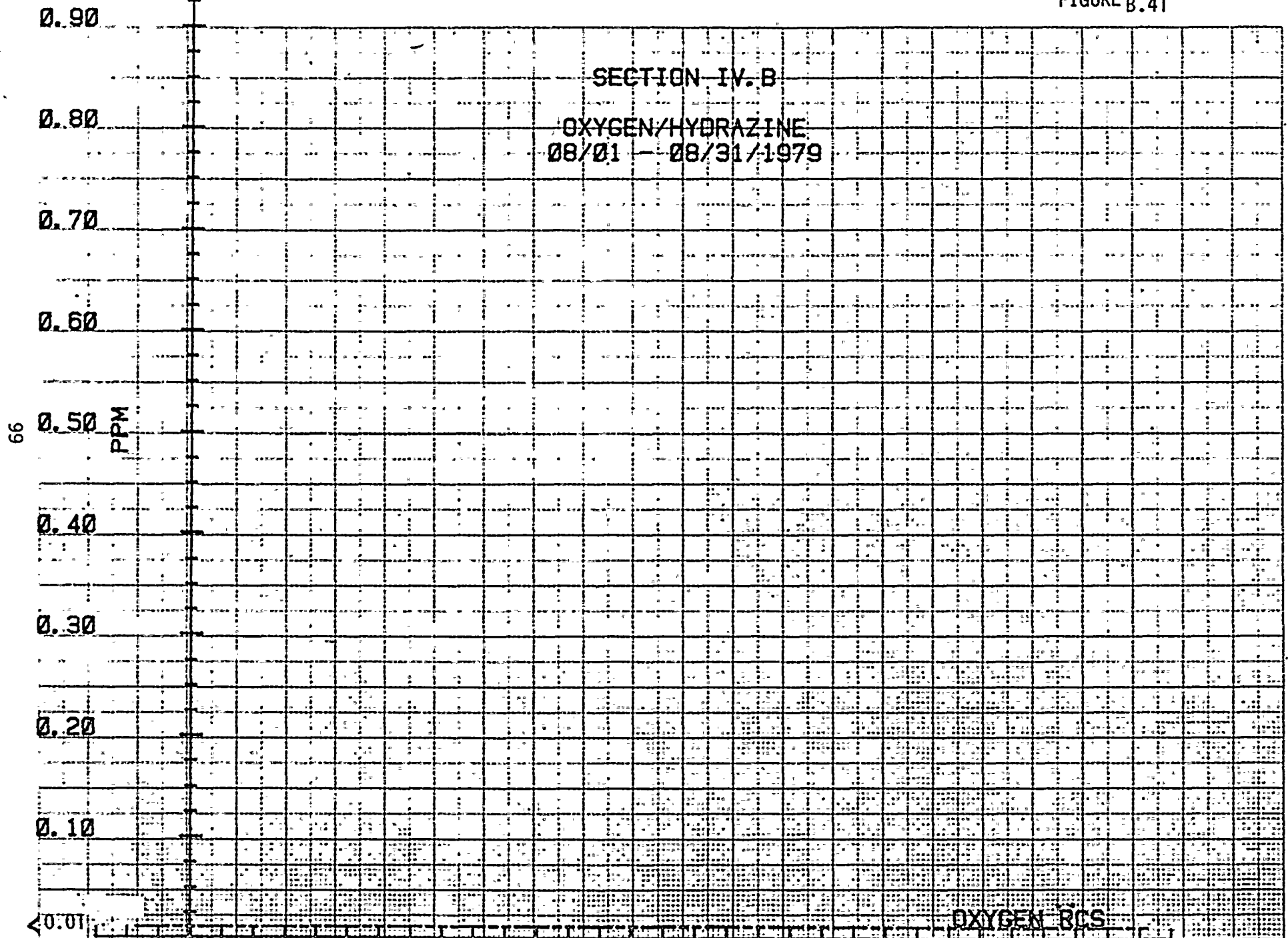


FIGURE B.41



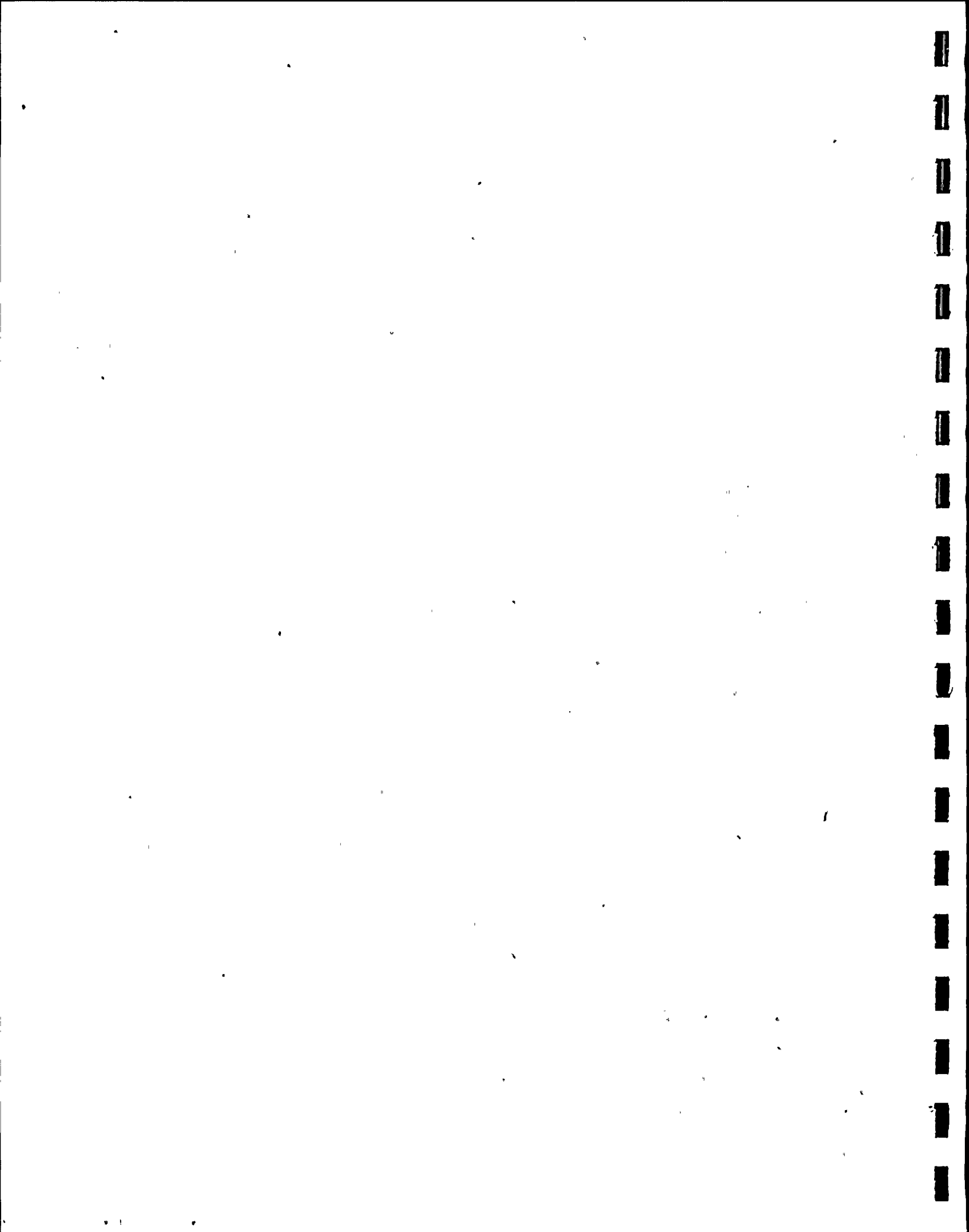
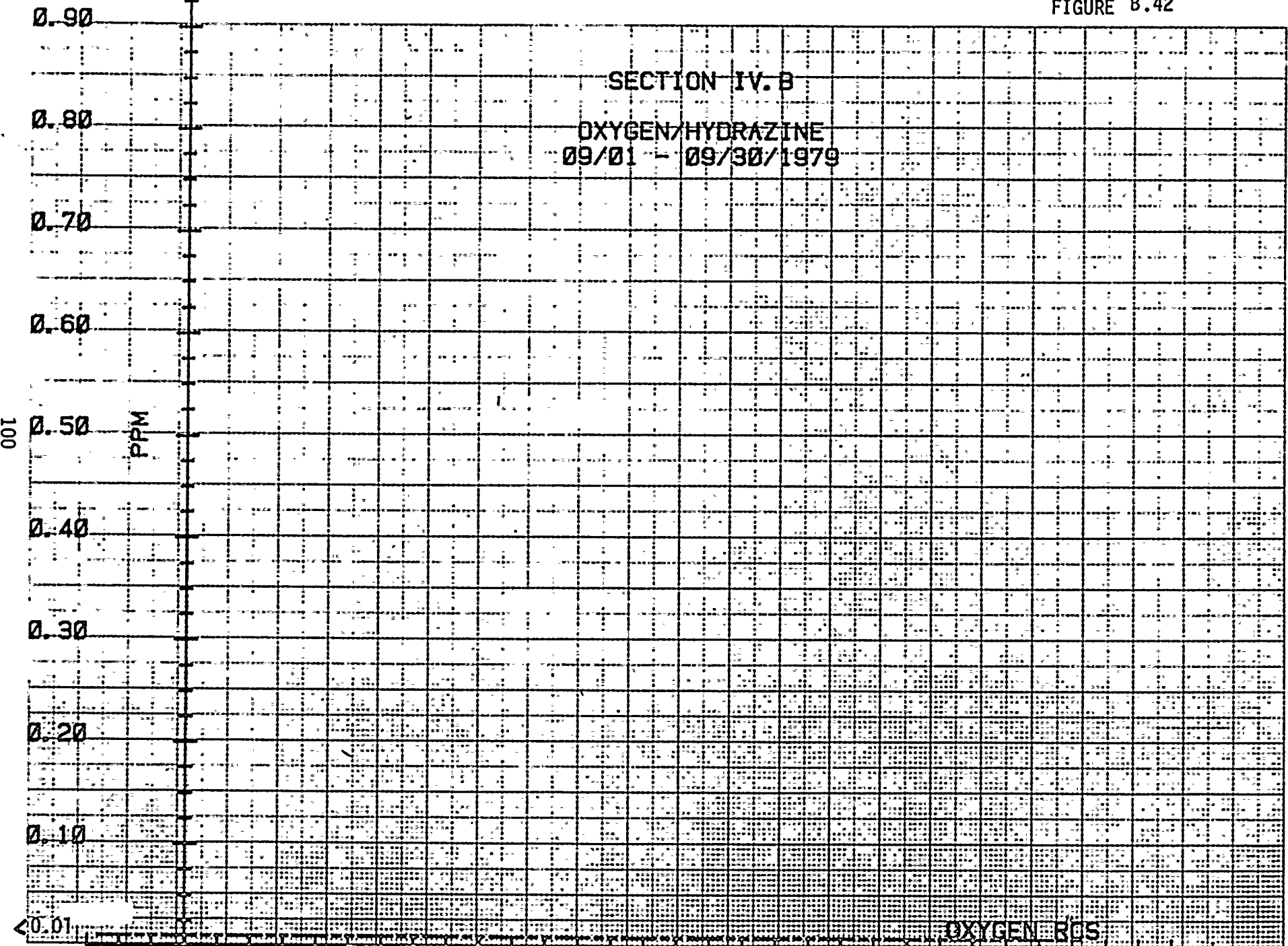


FIGURE B.42



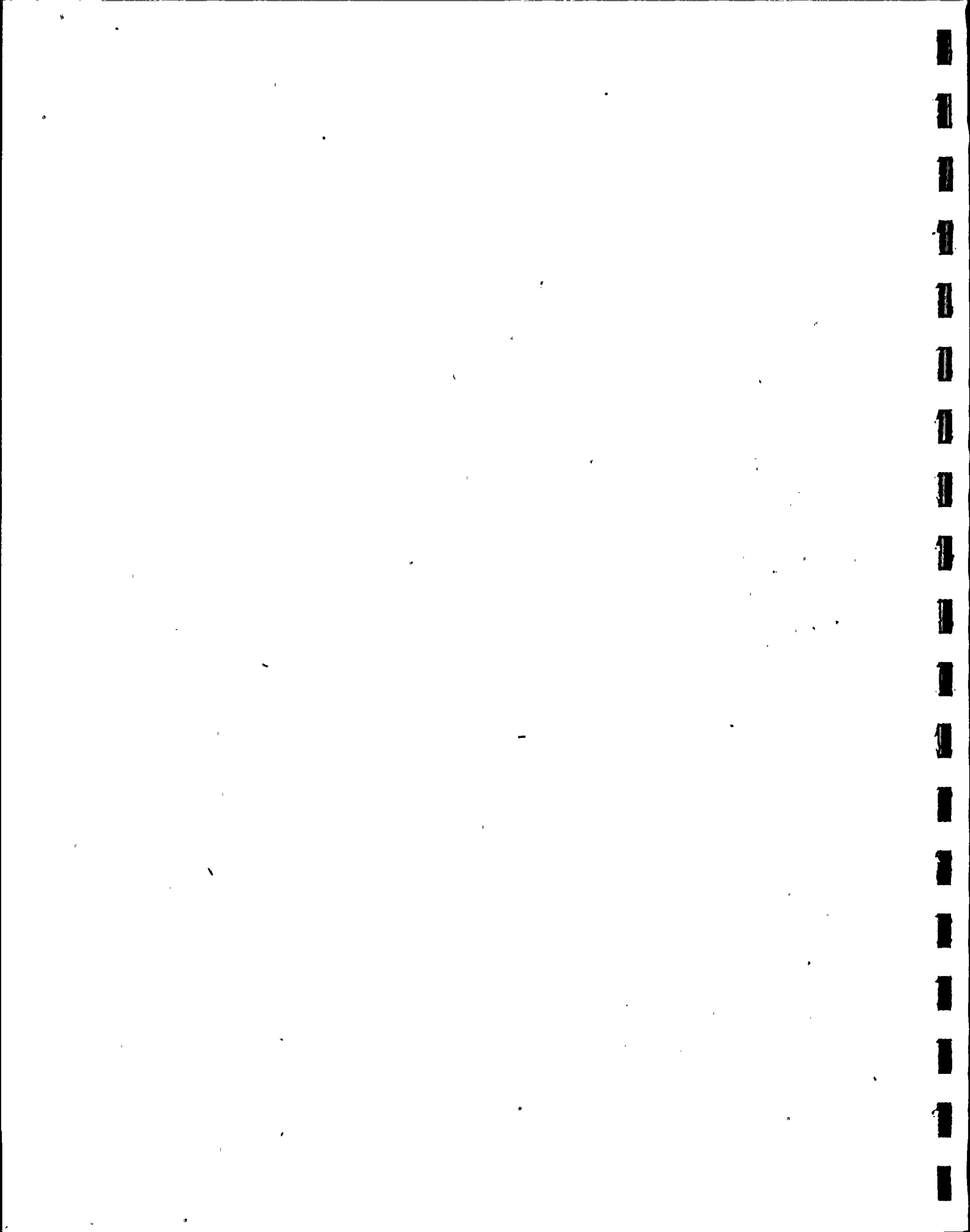


FIGURE B.43

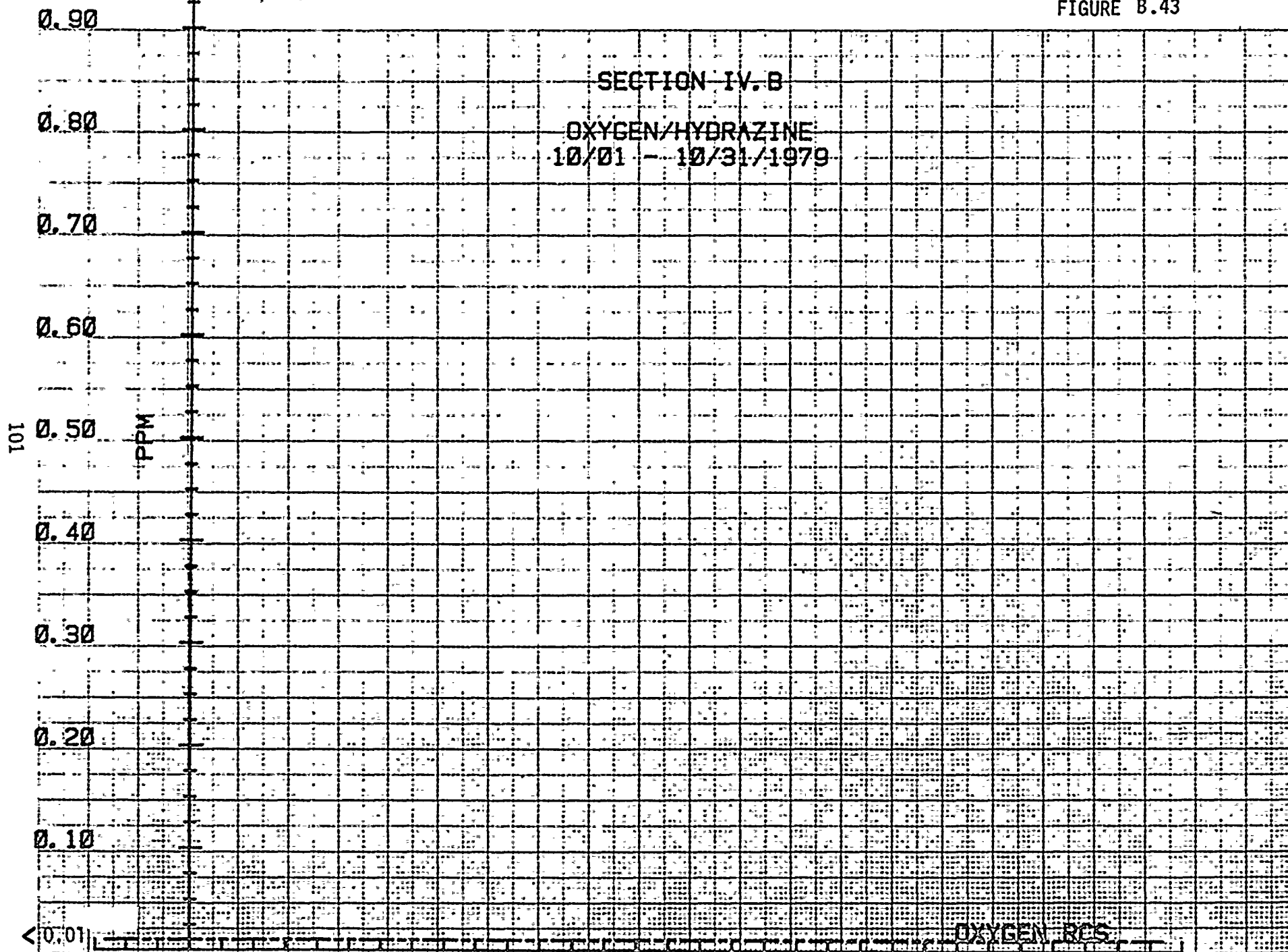


FIGURE B.44

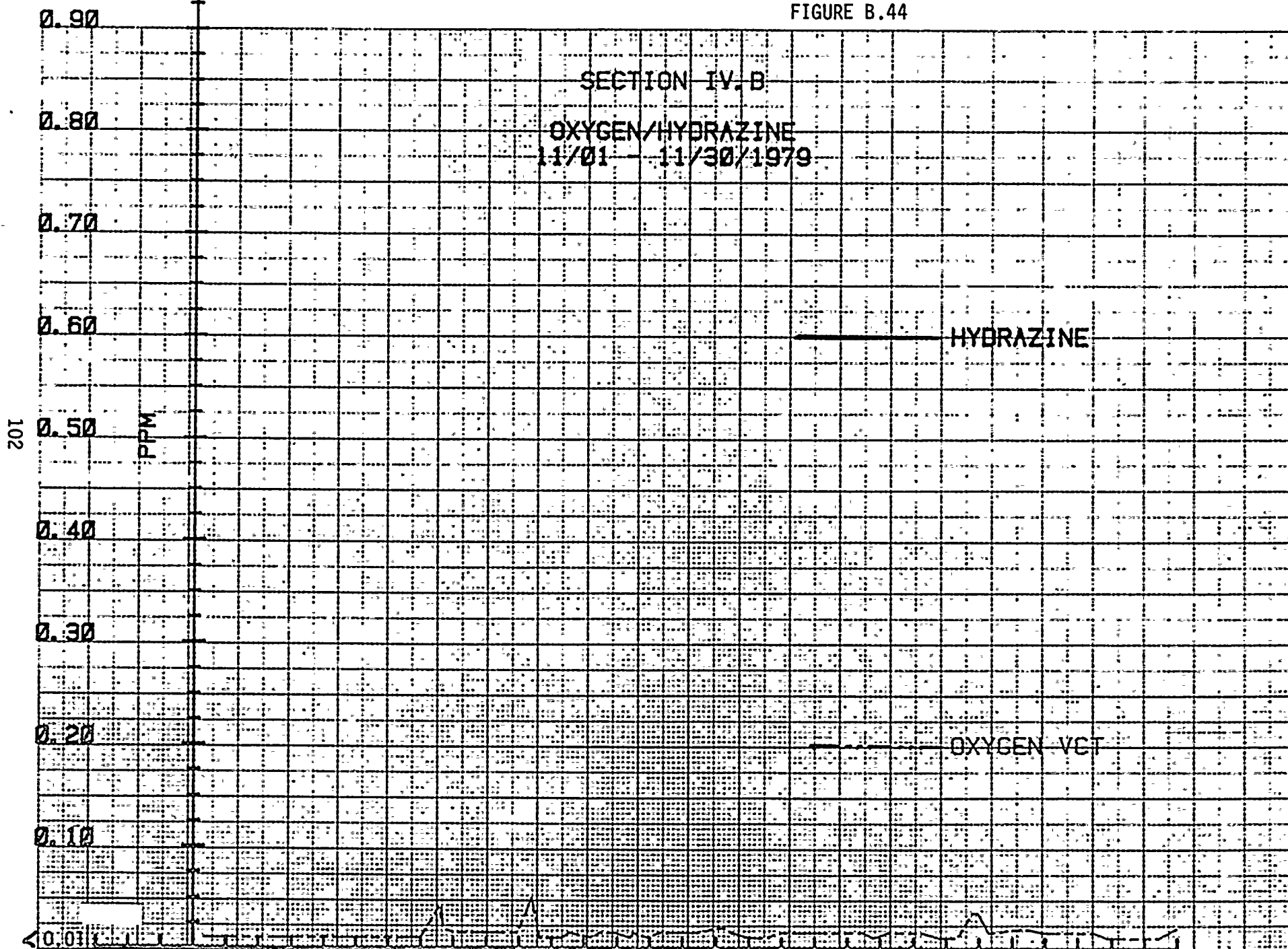


FIGURE B.45

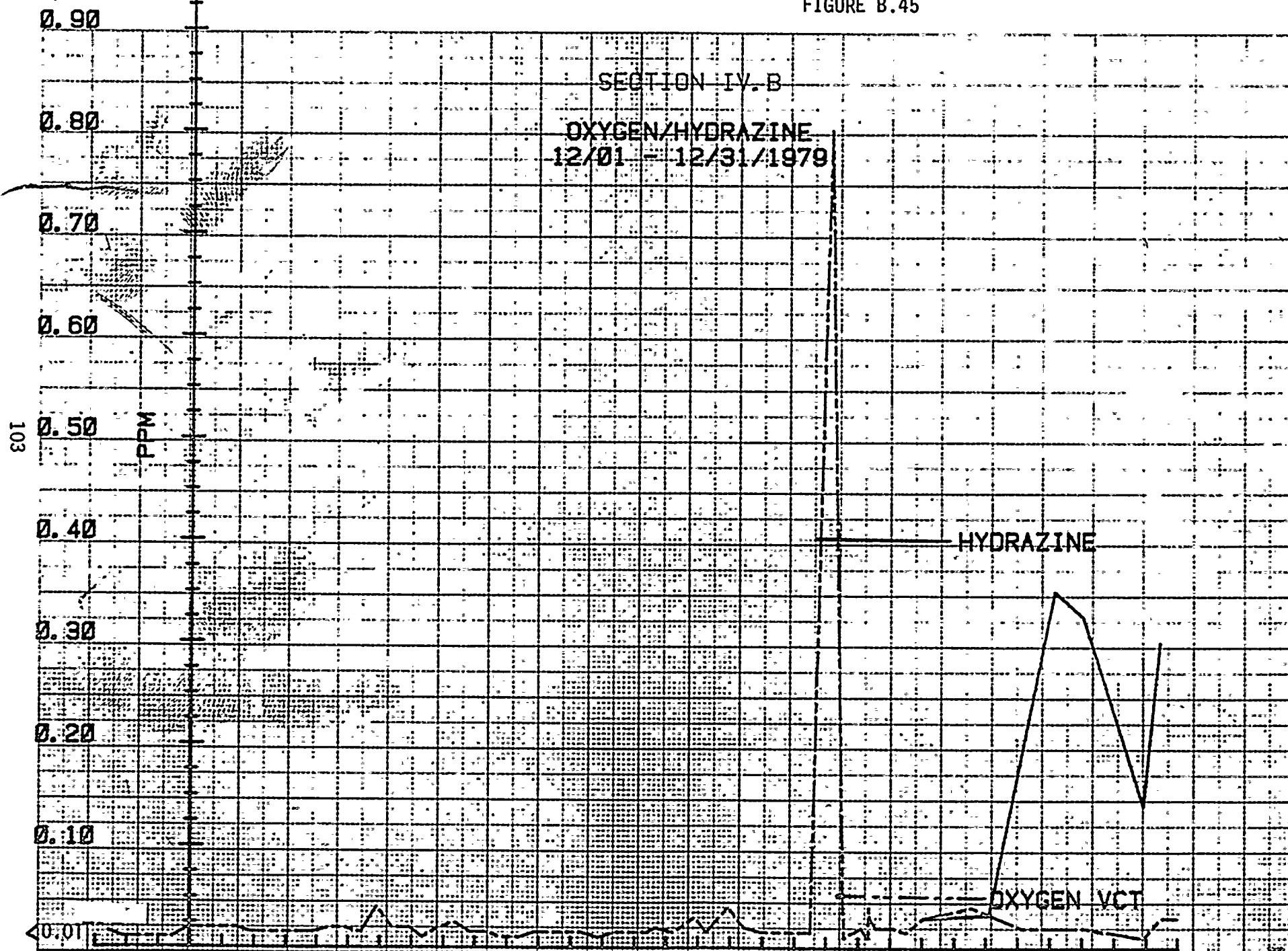


FIGURE B.46

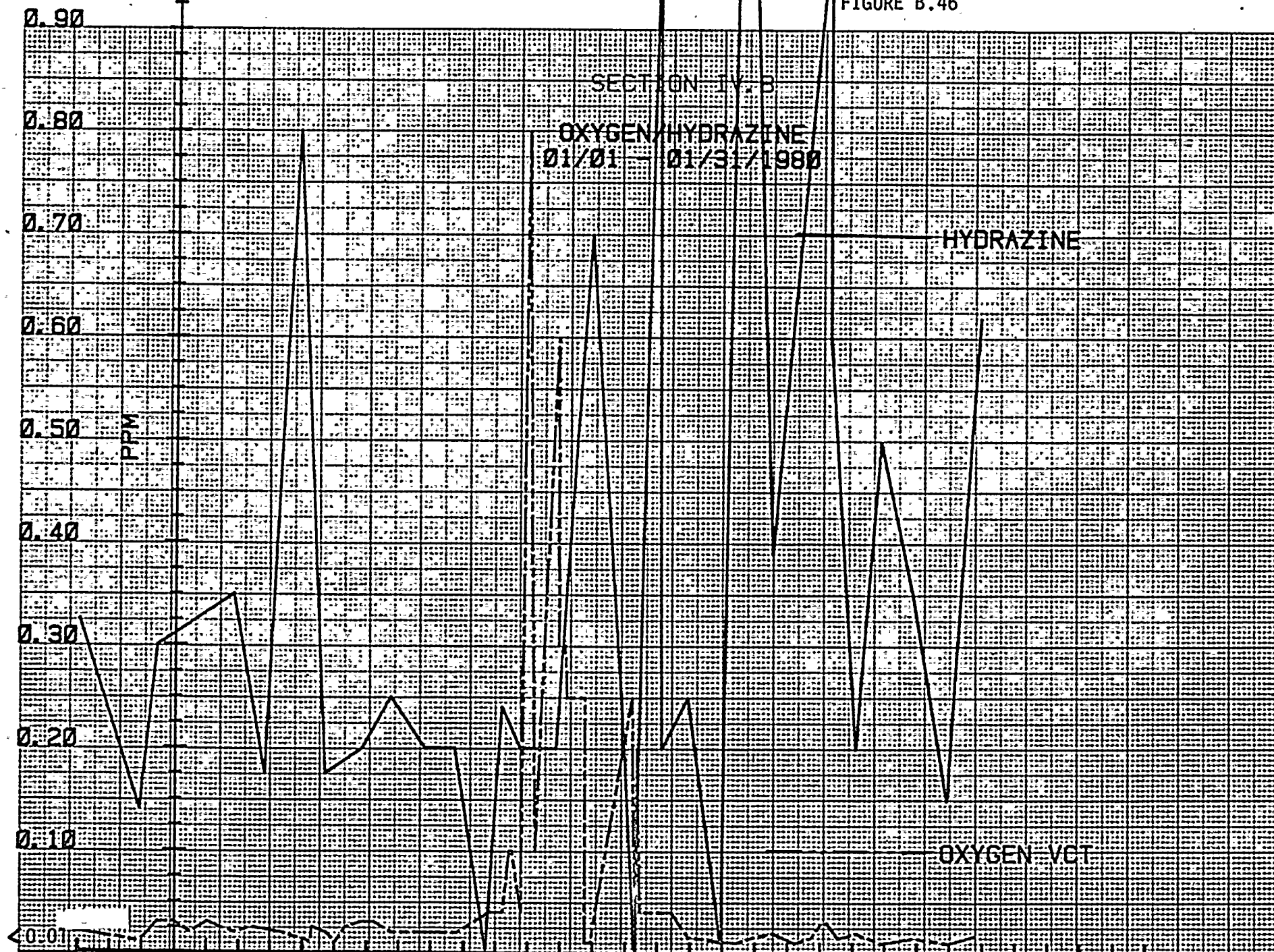
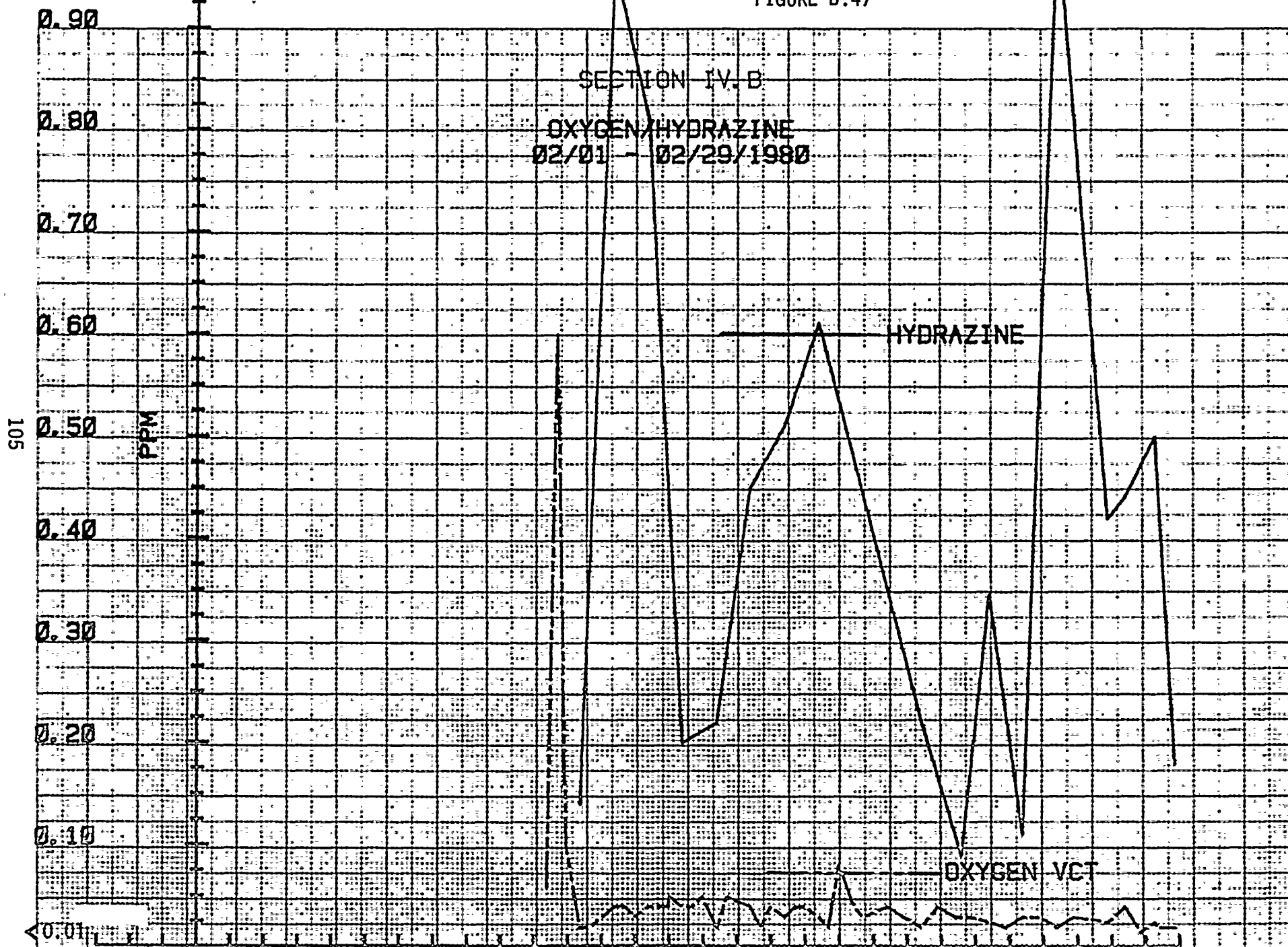




FIGURE B.47

SECTION IV.B
OXYGEN/HYDRAZINE
02/01 - 02/29/1980



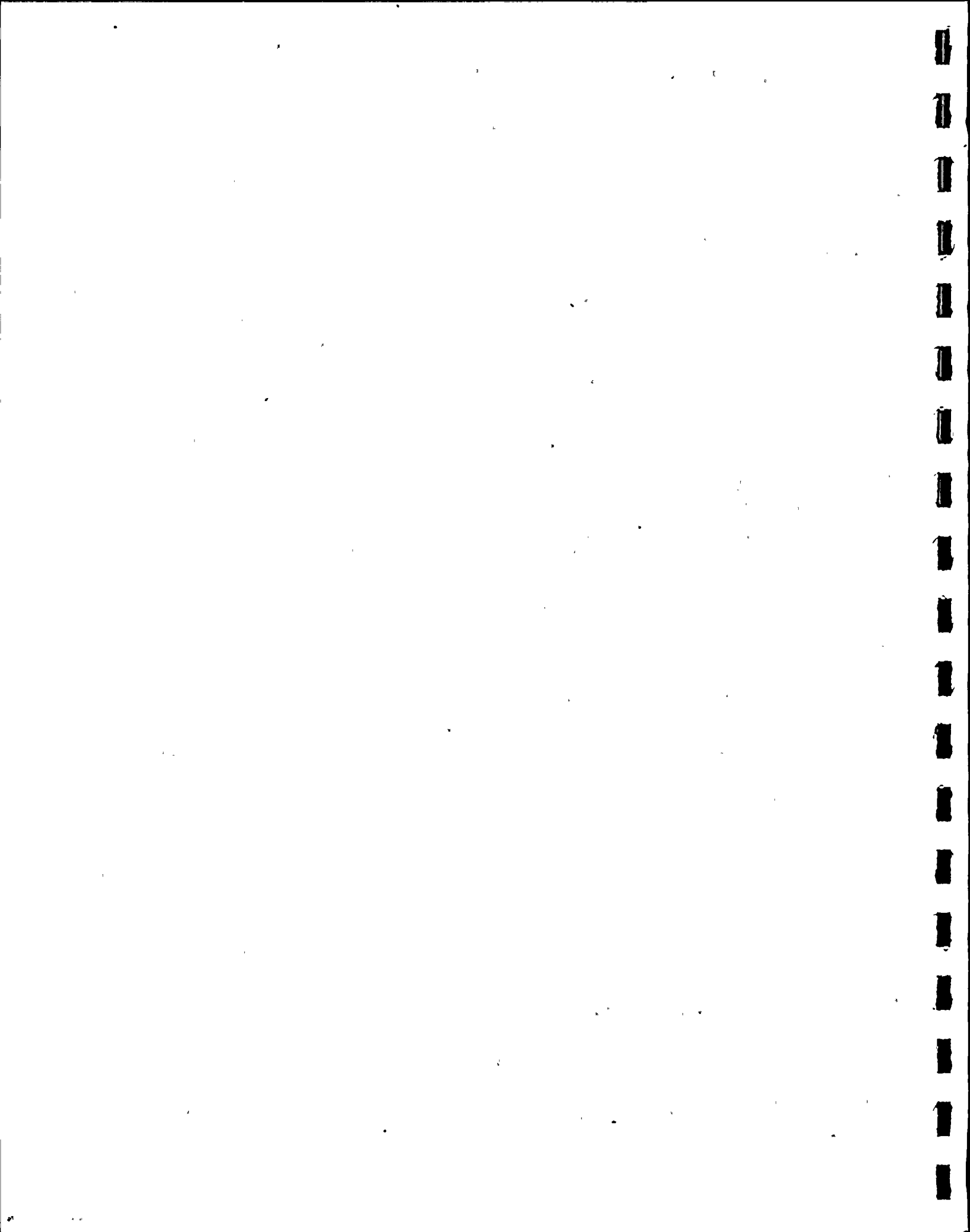
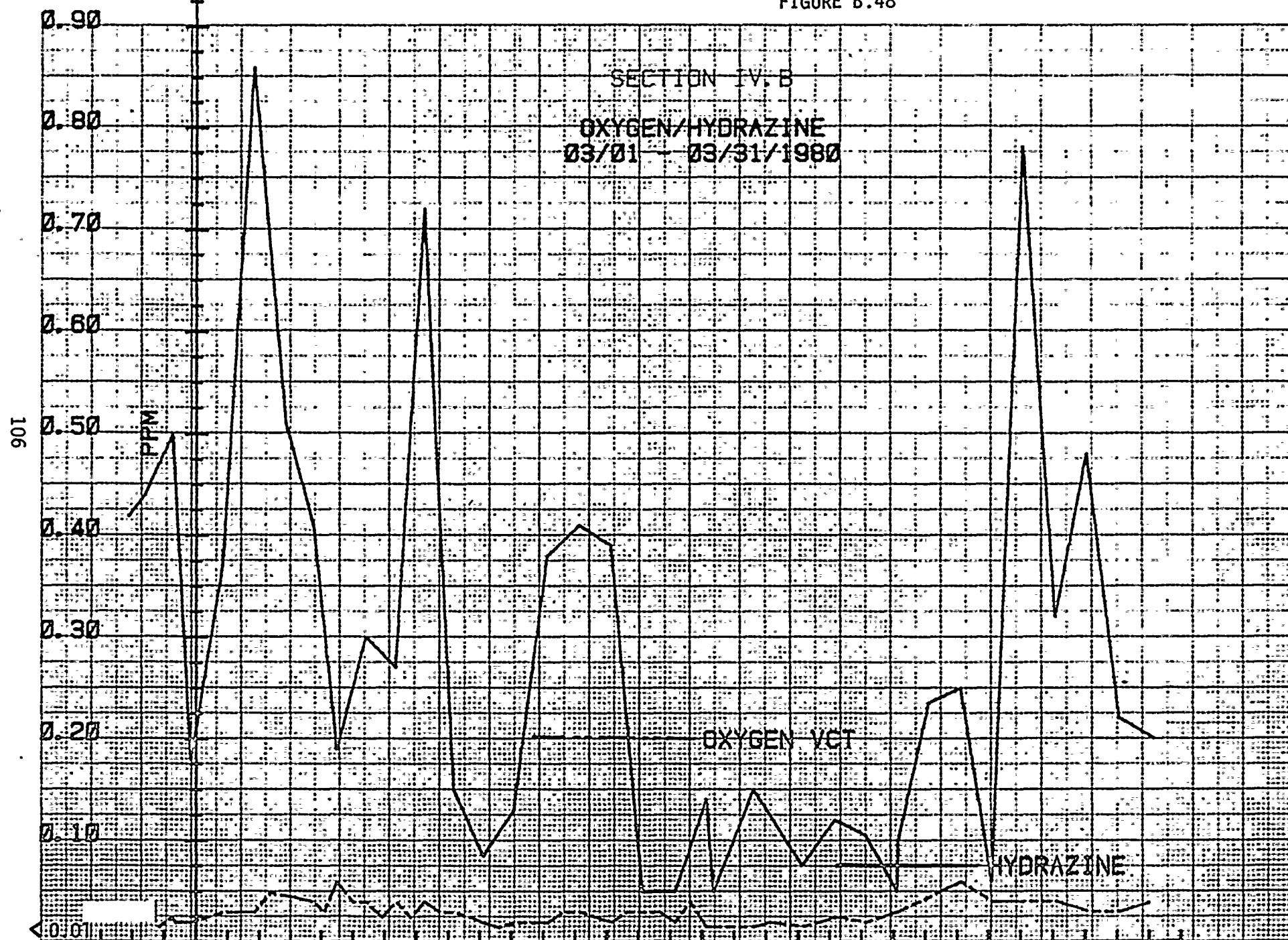


FIGURE B.48





g. Iodine Activity (Figures B.49-64)

Figures B.49 through B.64 depict iodine activity values obtained during the power distribution episode. Values obtained for the radio-nuclides Iodine-131 and Iodine-133, as well as the ratio of I-131 to I-133 showed normal variation with plant conditions.

Fluctuations due to power transients and operation of the purification system were as expected.



FIGURE B.49

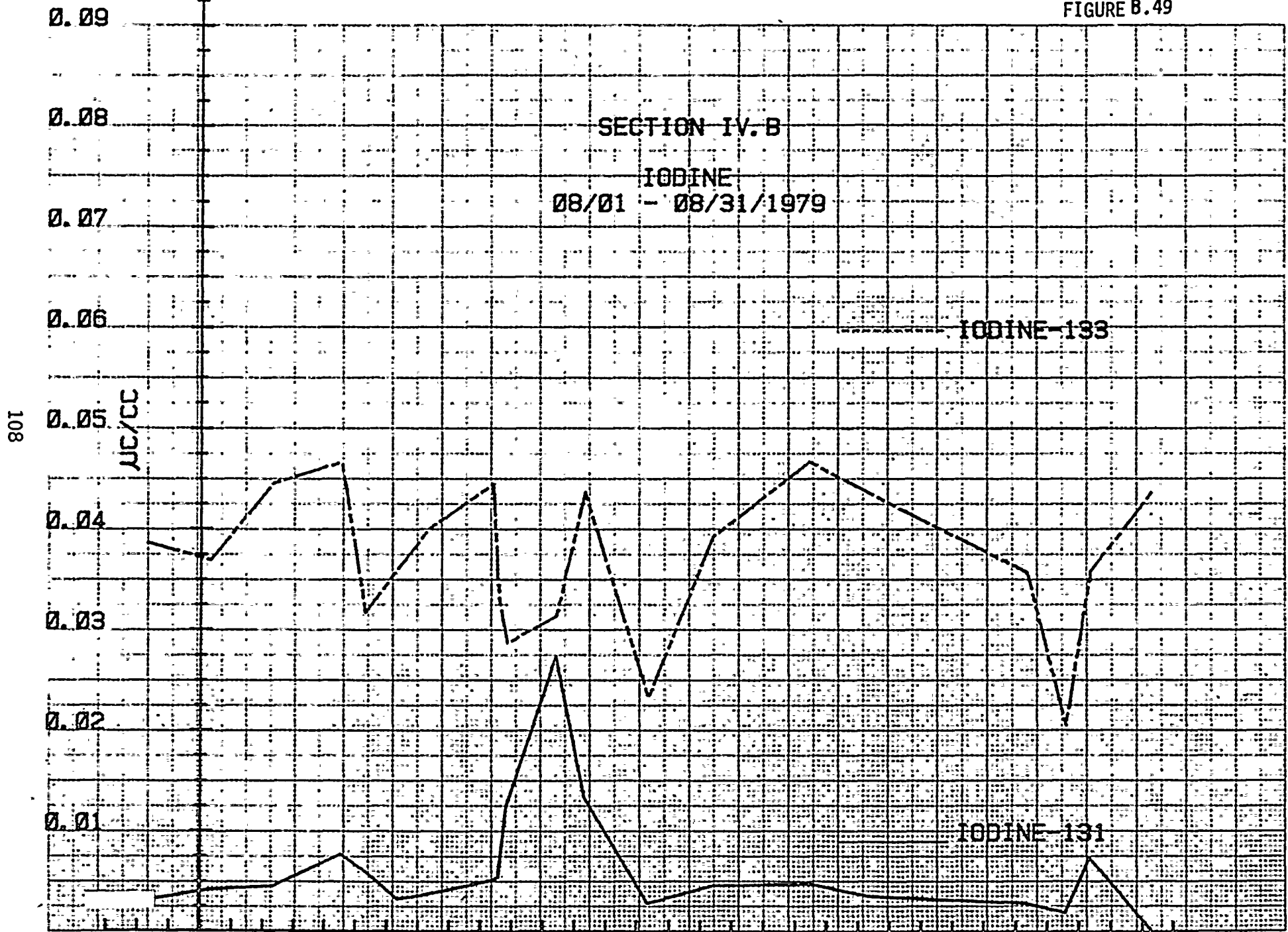


FIGURE B.50

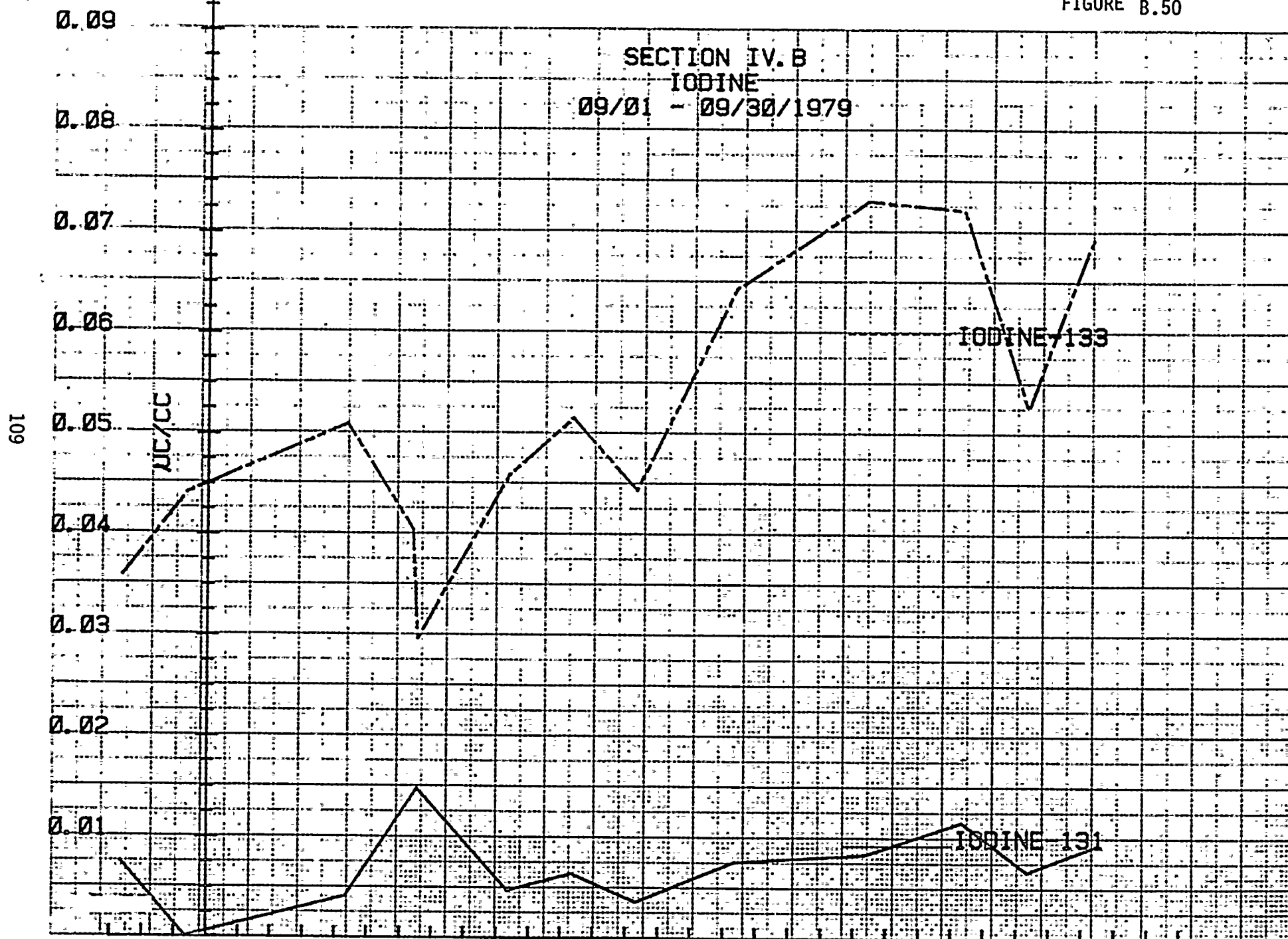


FIGURE B.51

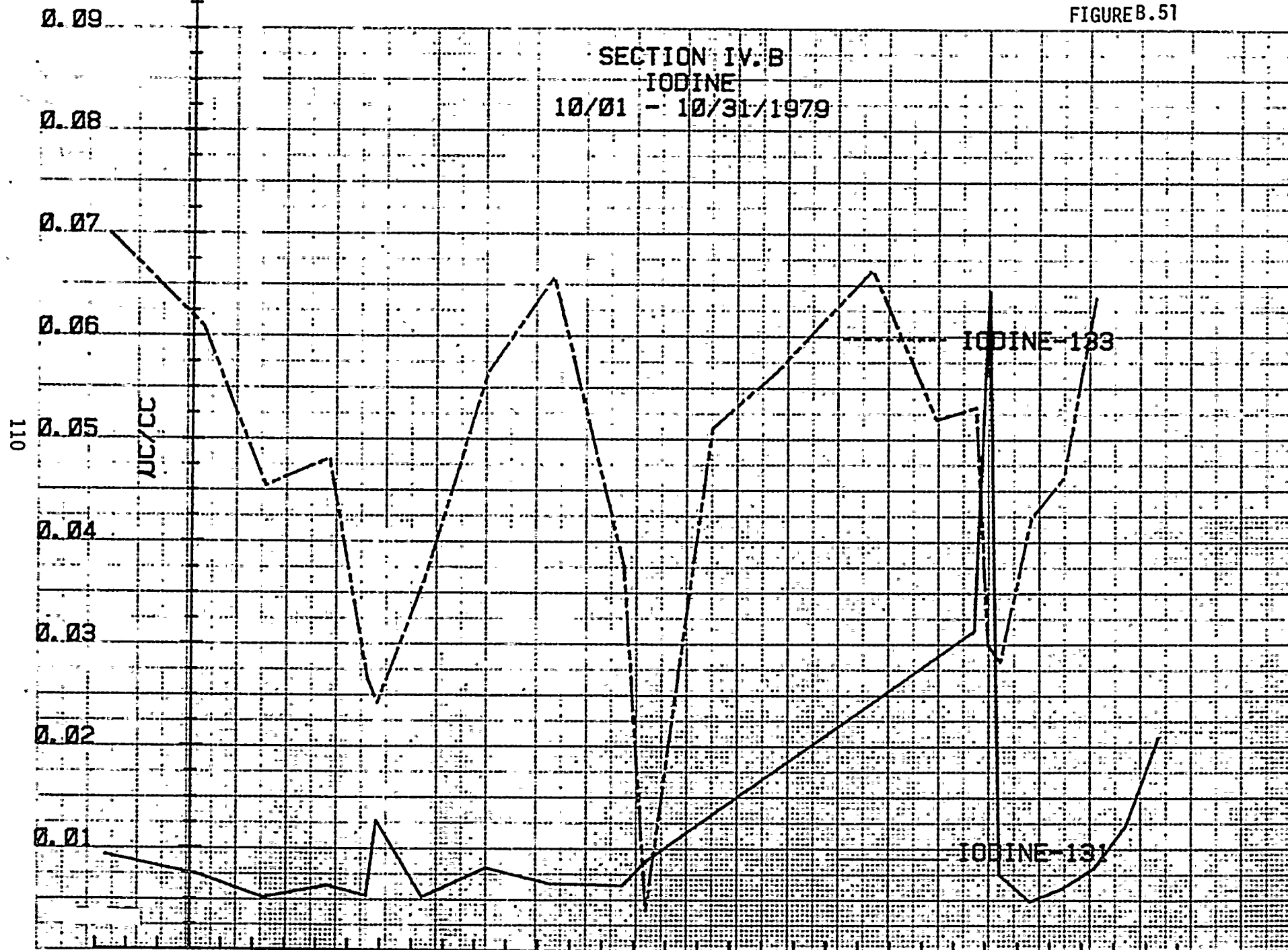




FIGURE B.52

SECTION IV. B

IODINE

11/01 - 11/30/1979

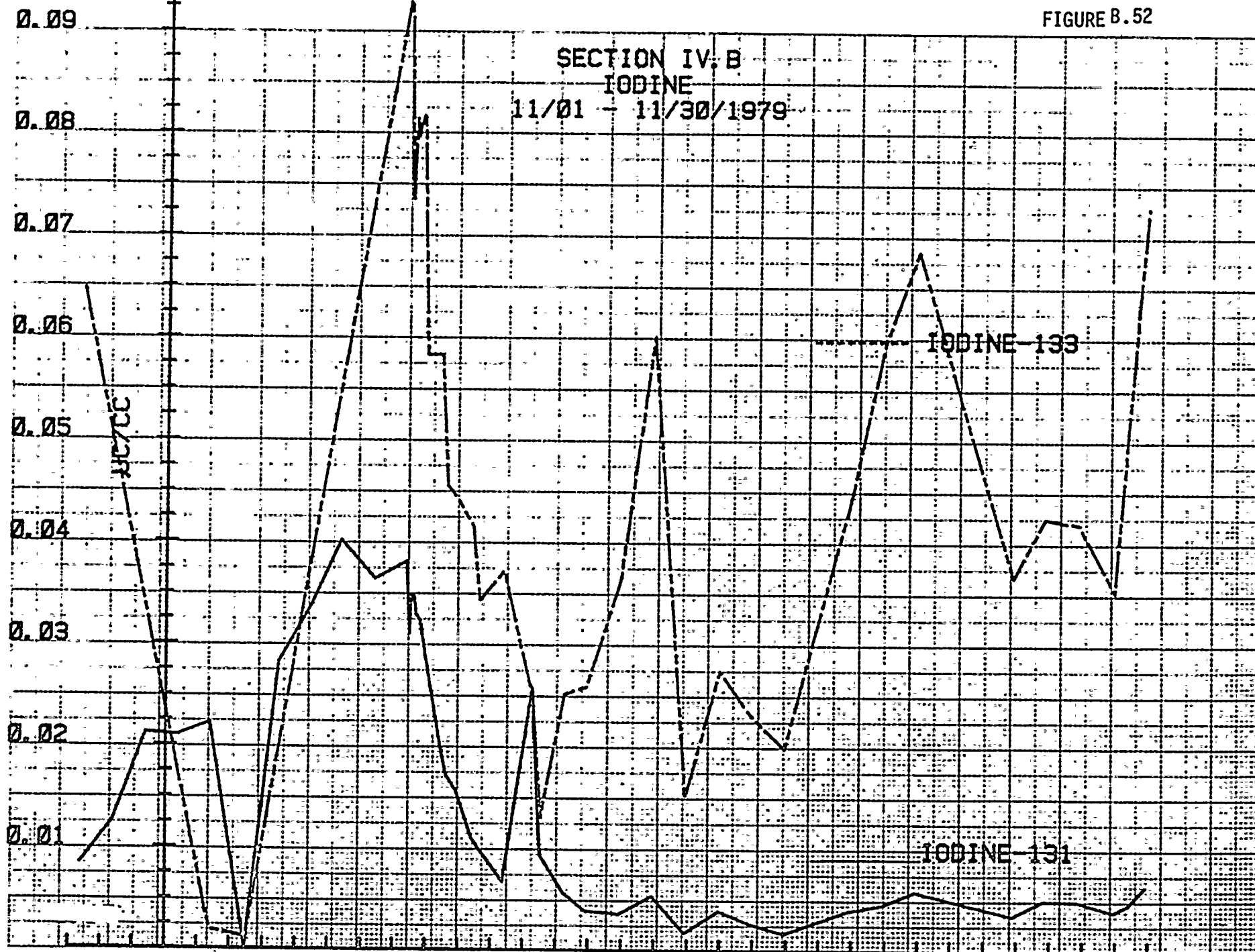




FIGURE B.53

112

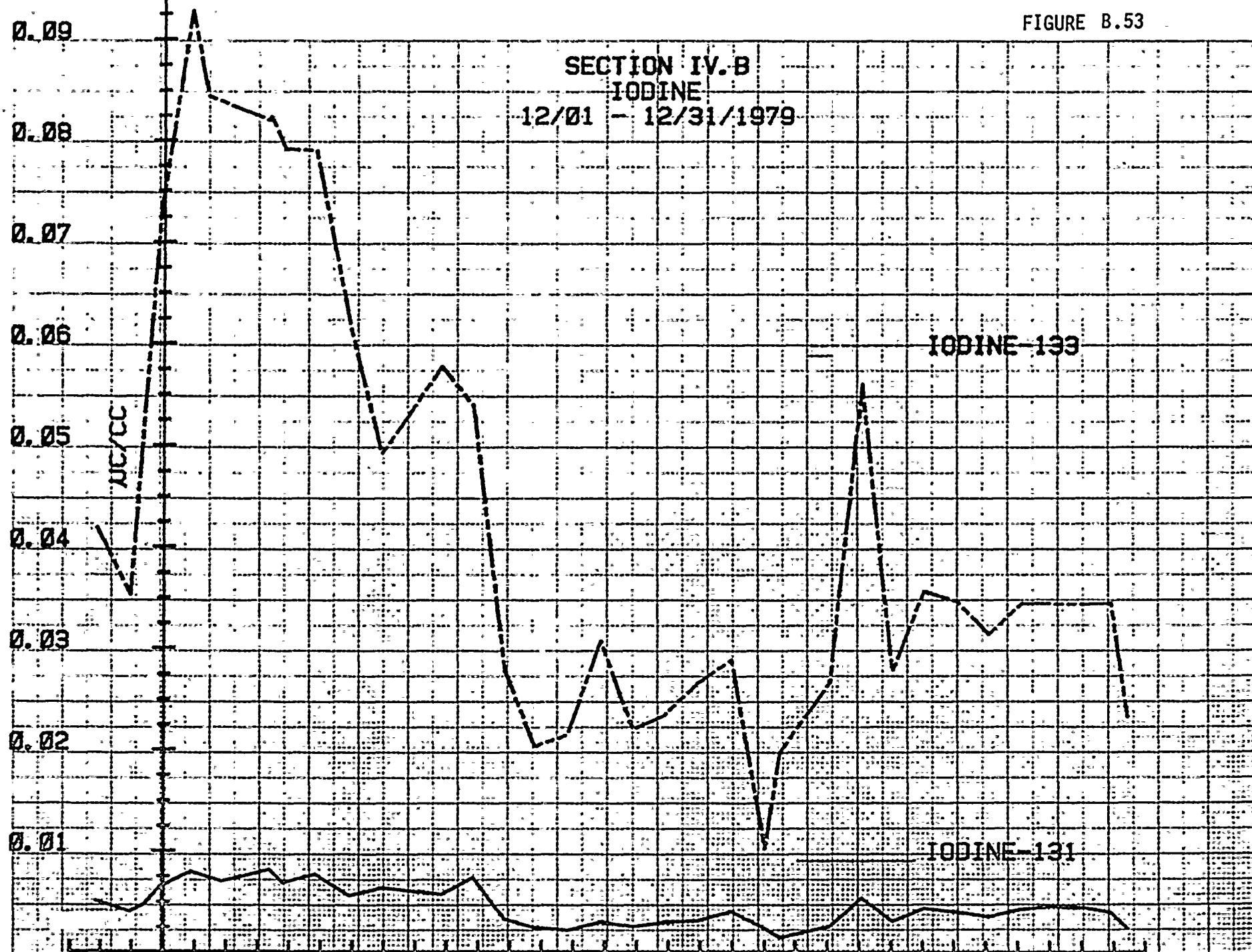




FIGURE B.54

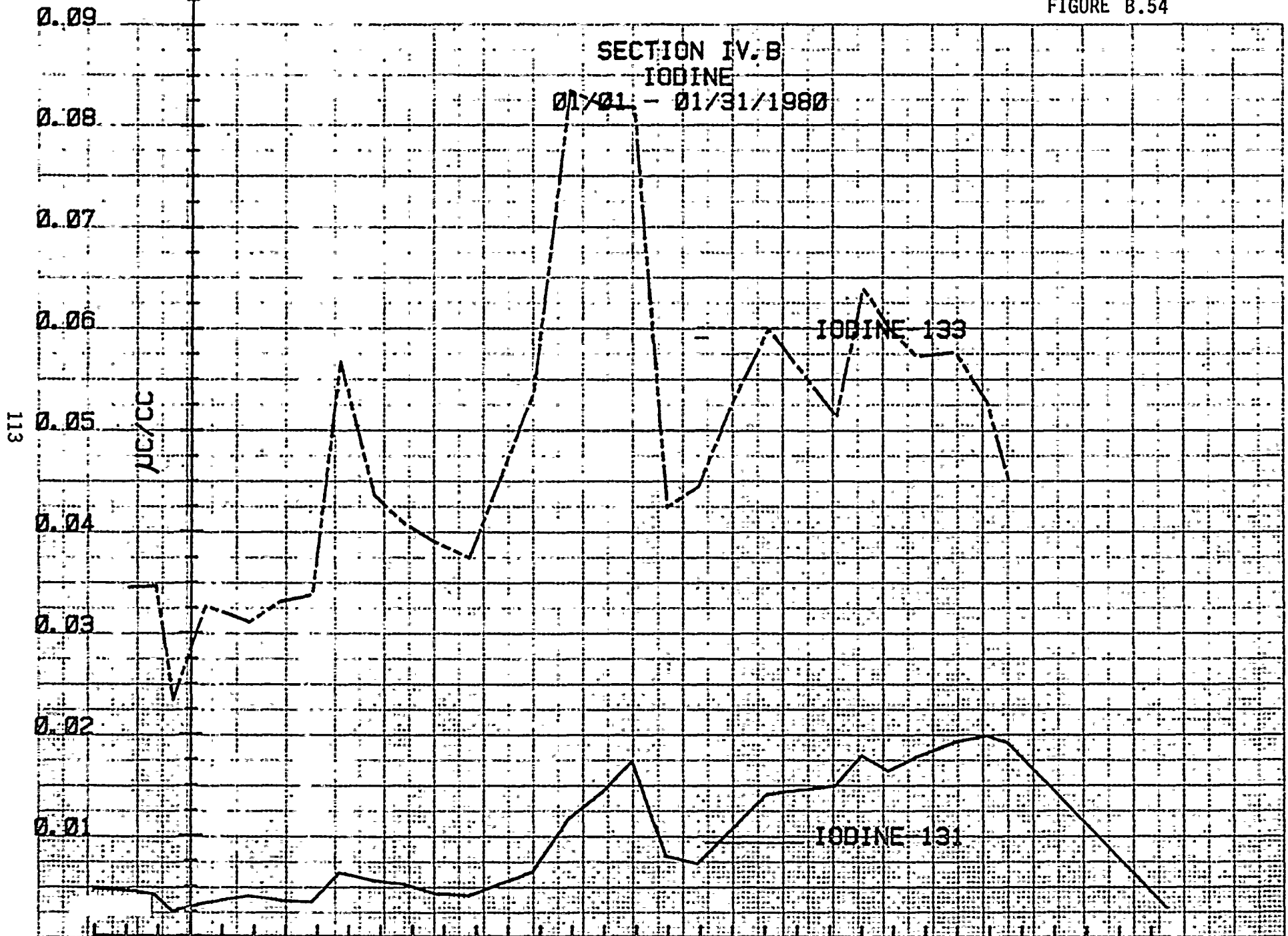
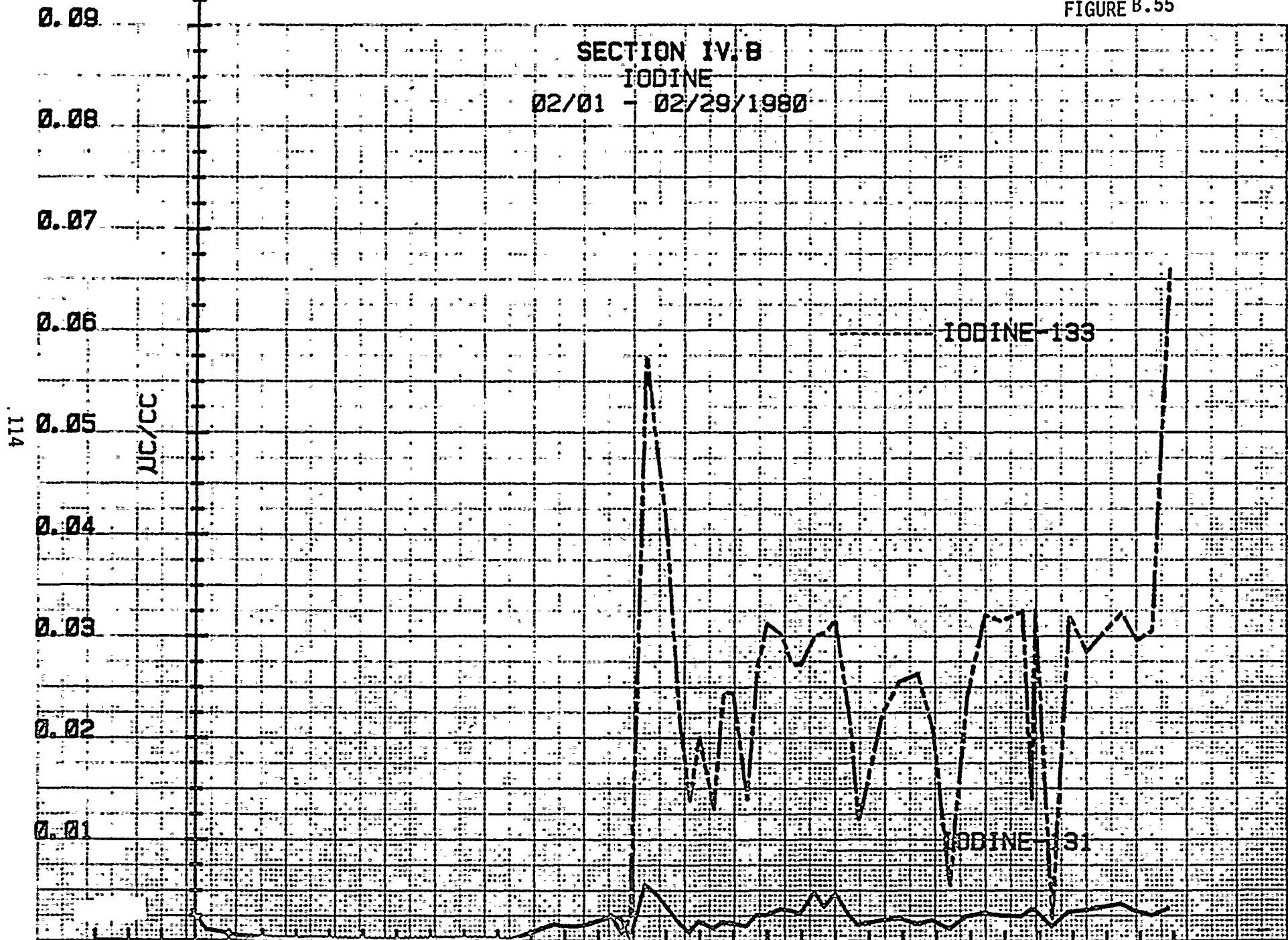




FIGURE B.55

SECTION IV. B
IODINE
02/01 - 02/29/1980



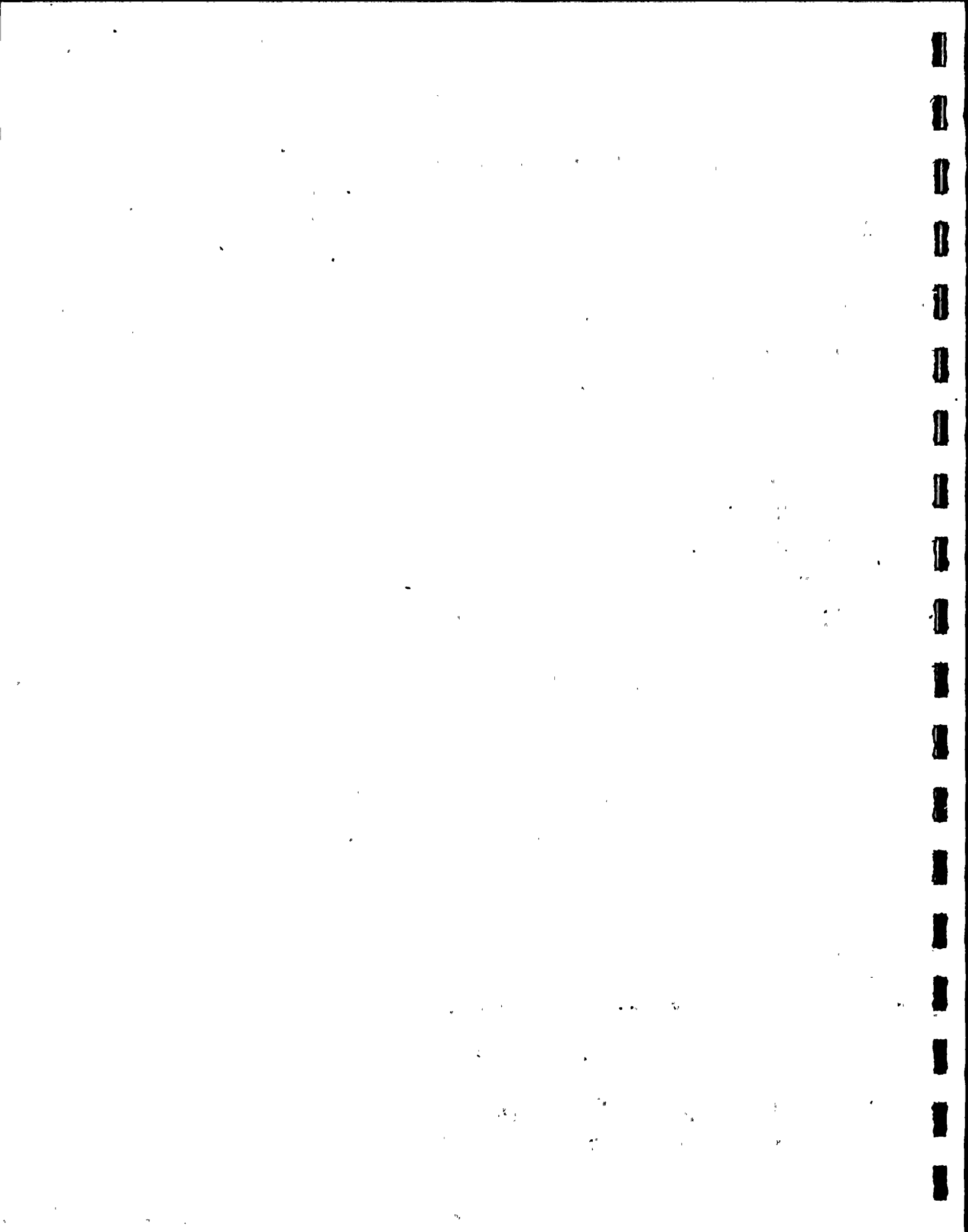


FIGURE B.56

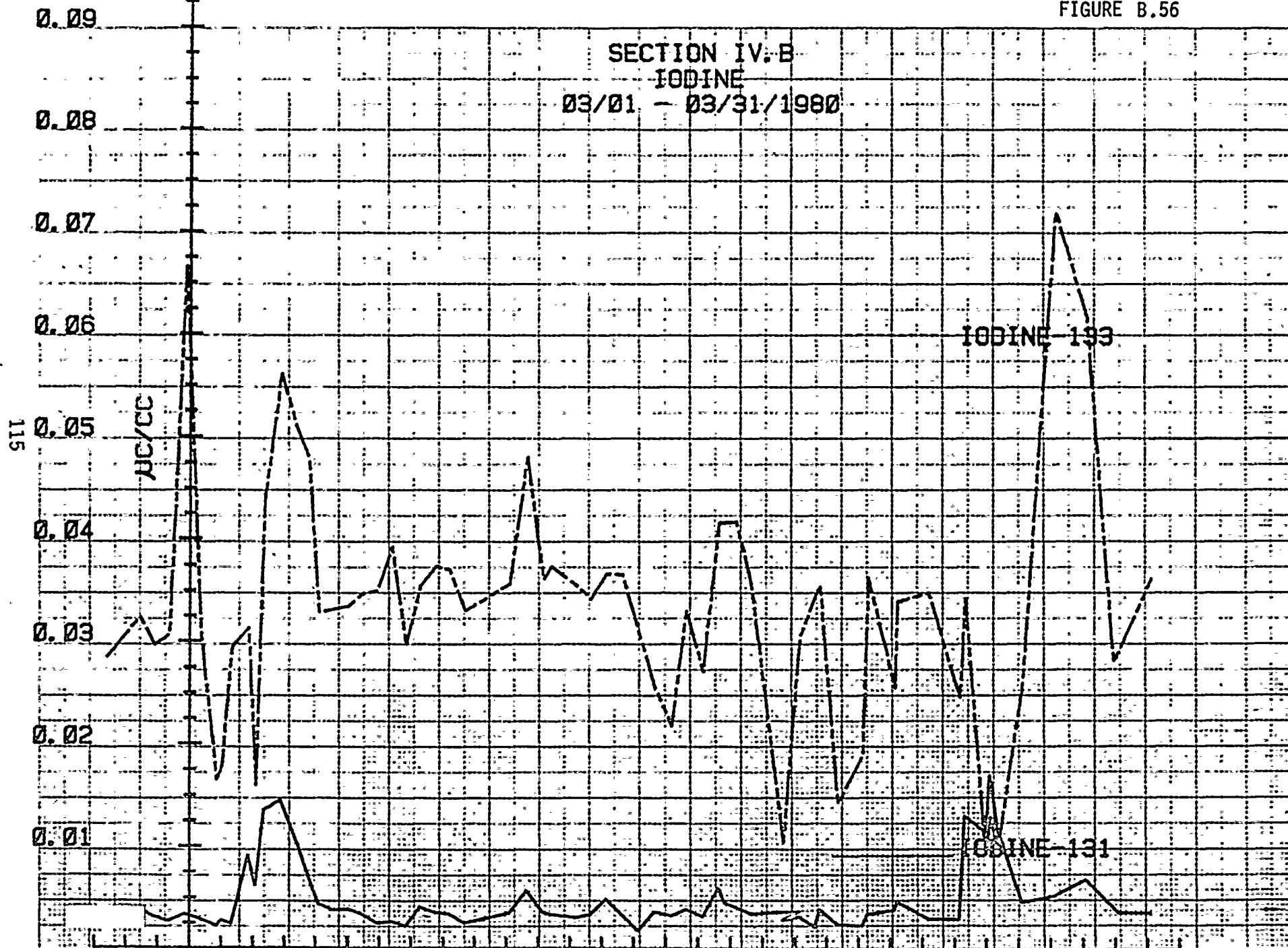
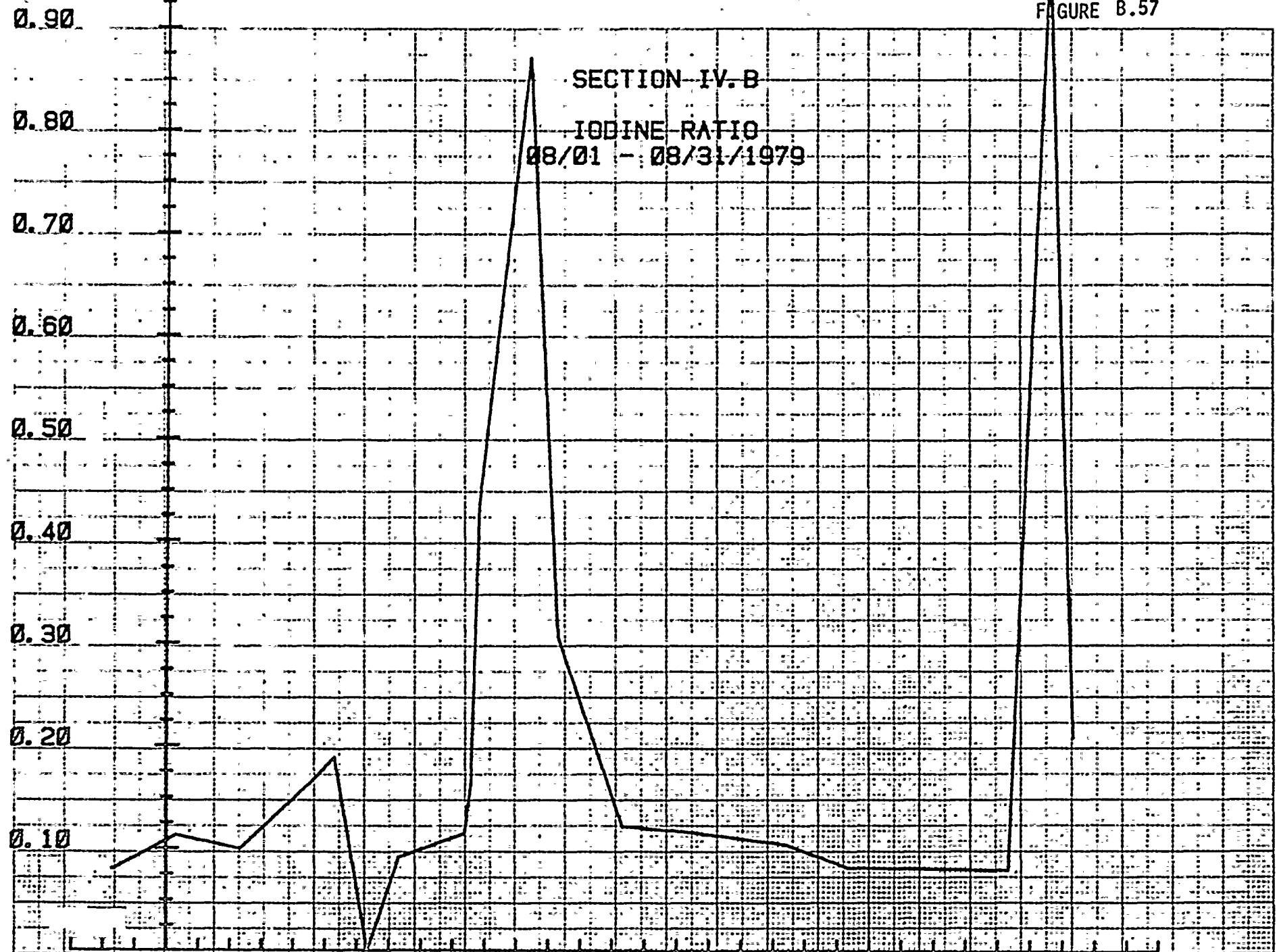


FIGURE B.57



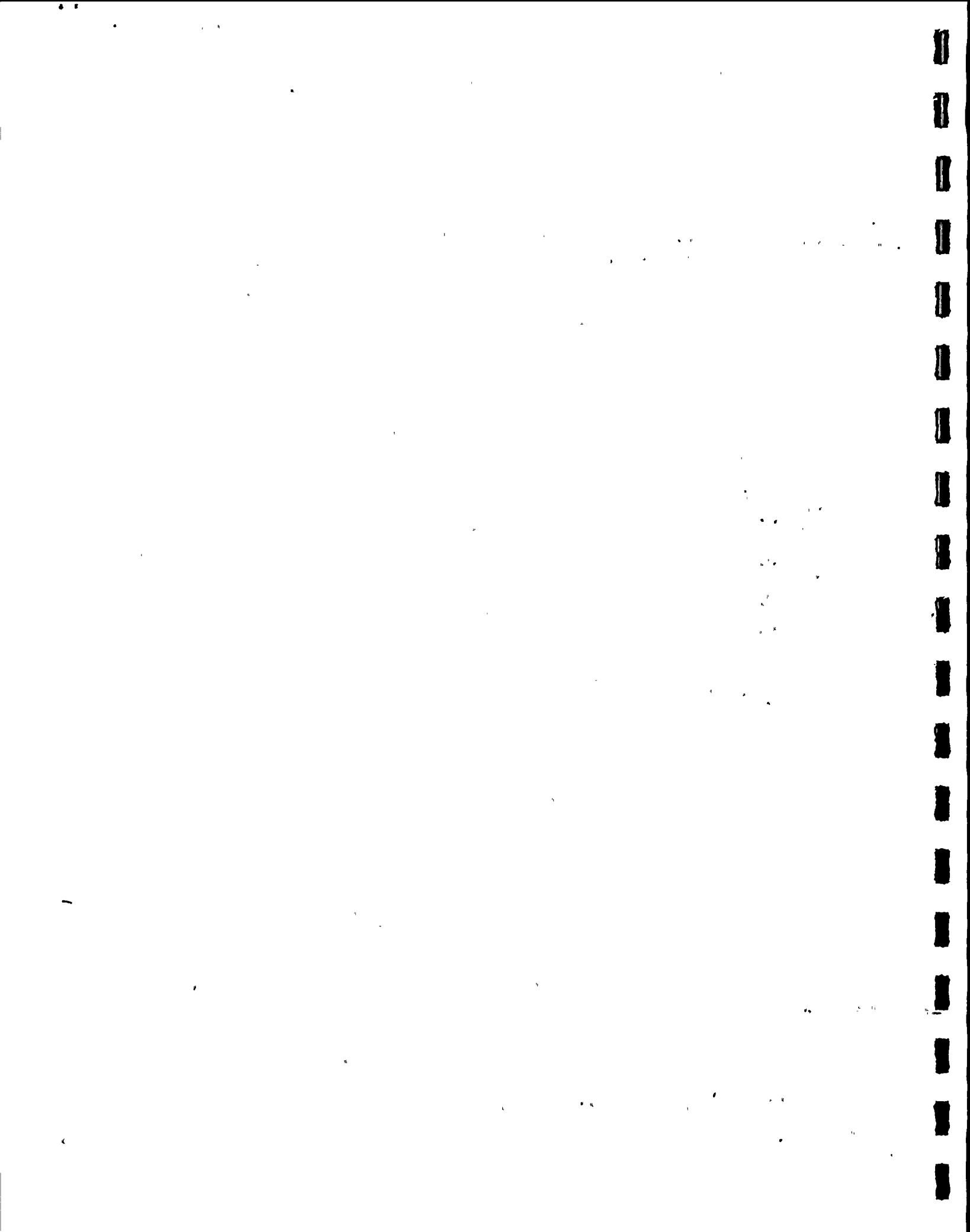


FIGURE B.58

SECTION IV. B
 IODINE RATIO
 09/01 - 09/30/1979

117

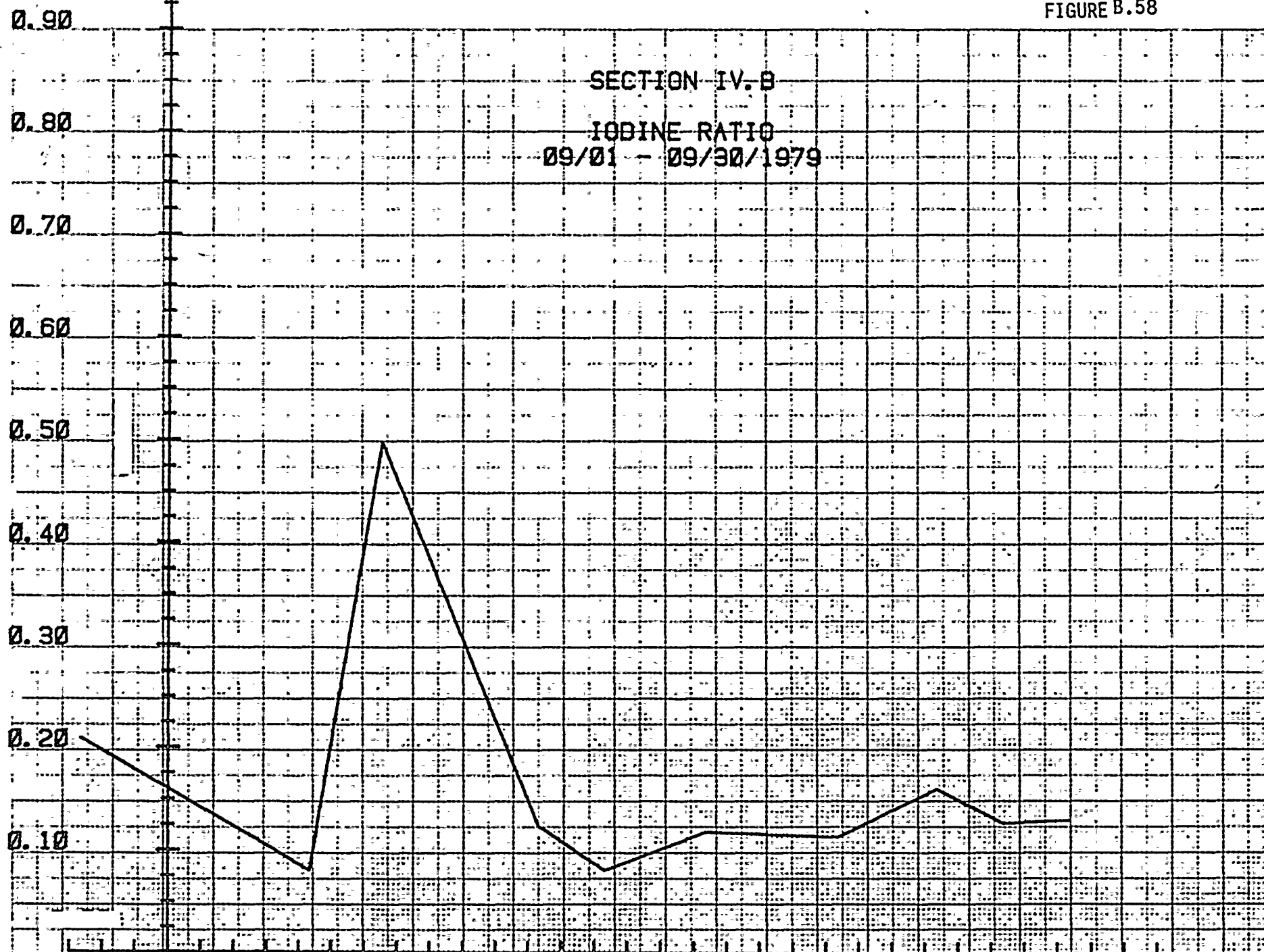
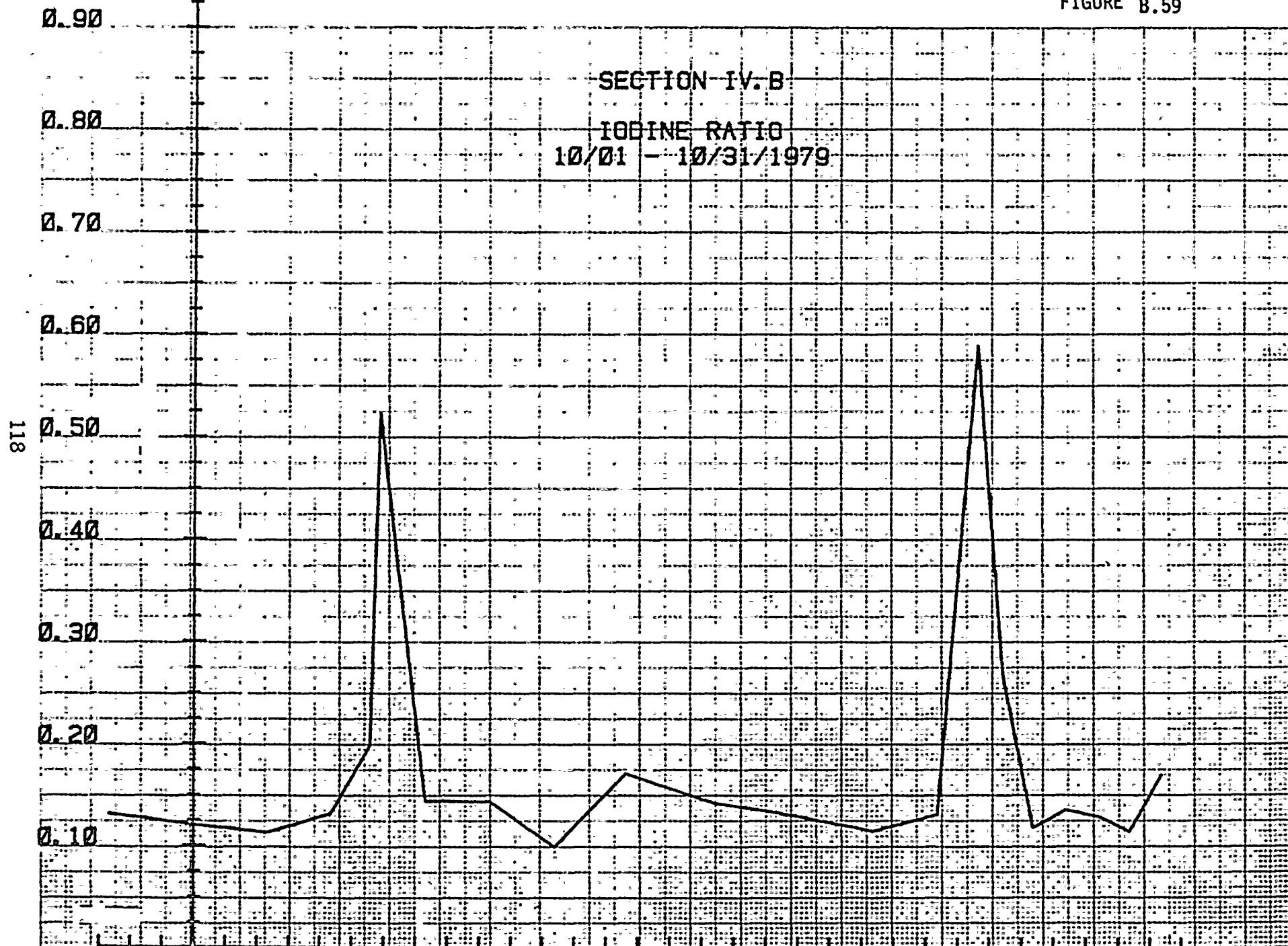


FIGURE B.59



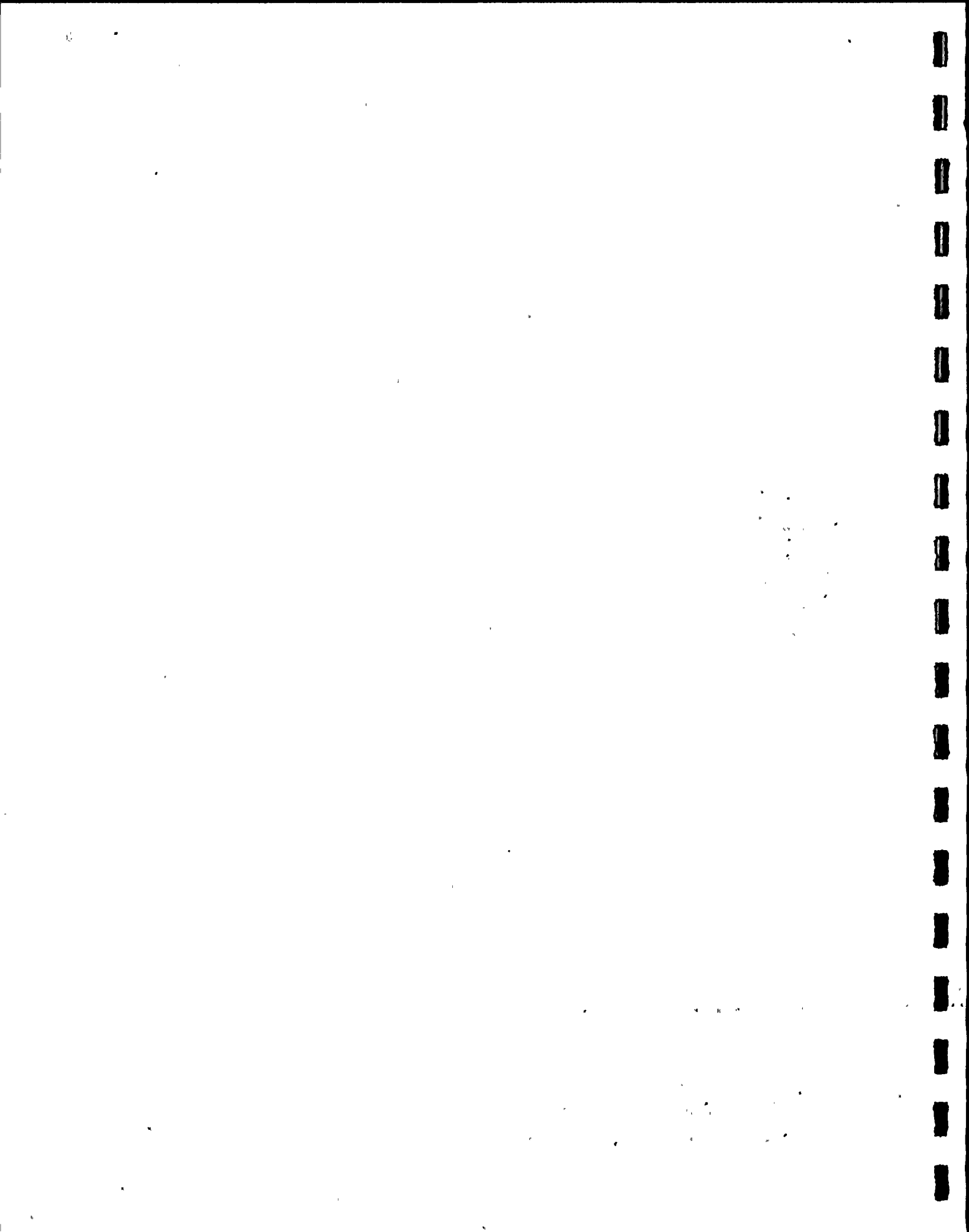
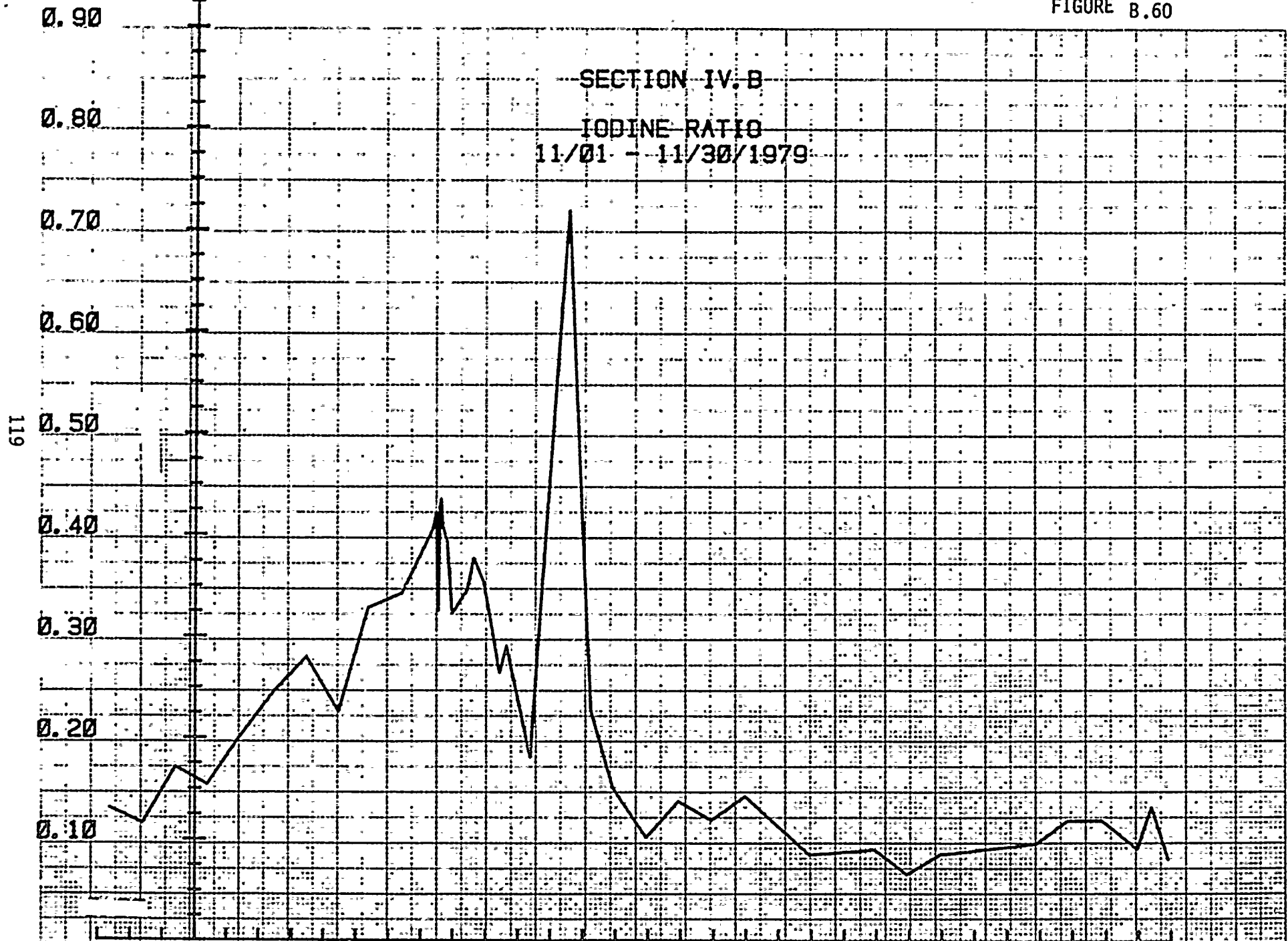


FIGURE B.60



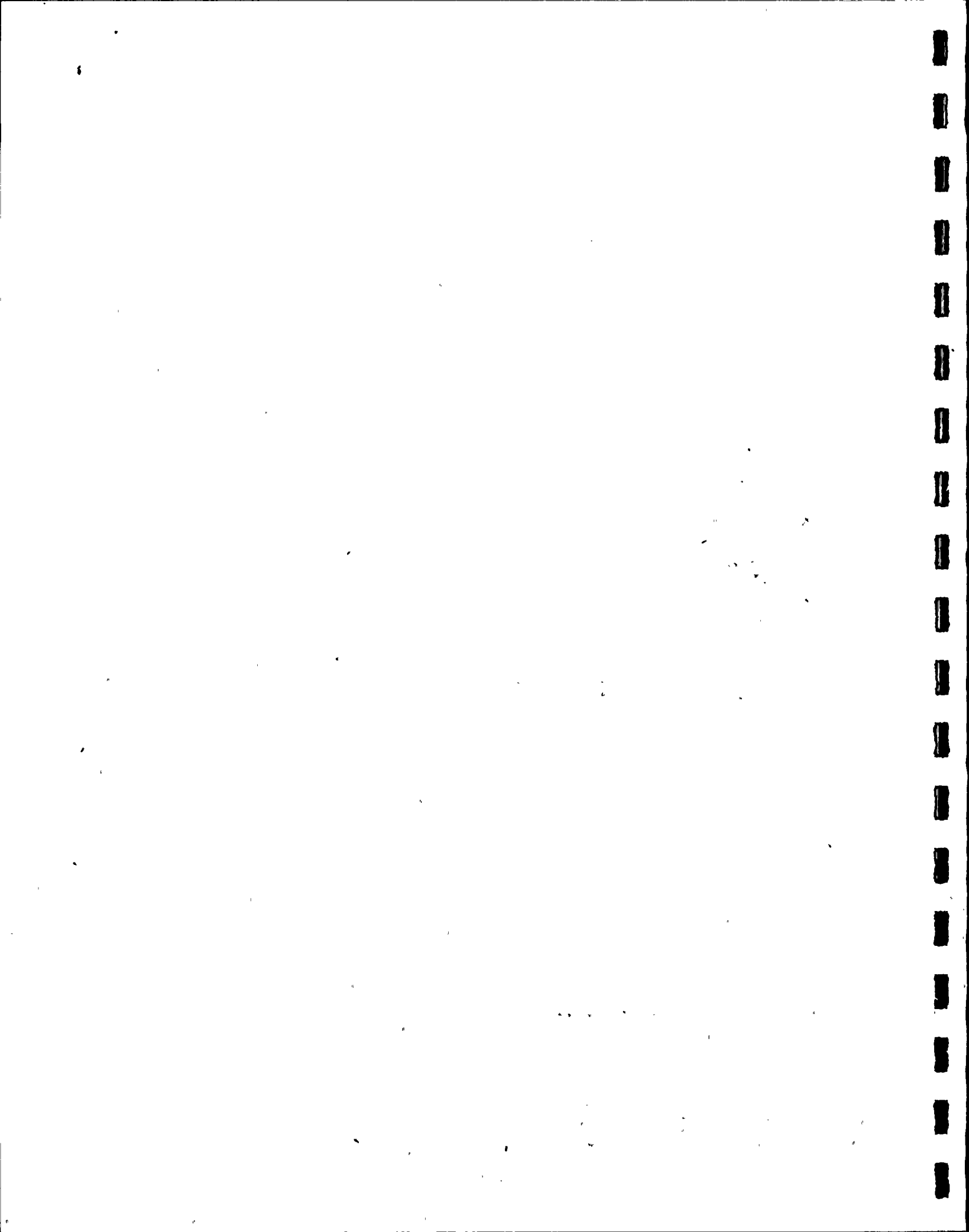
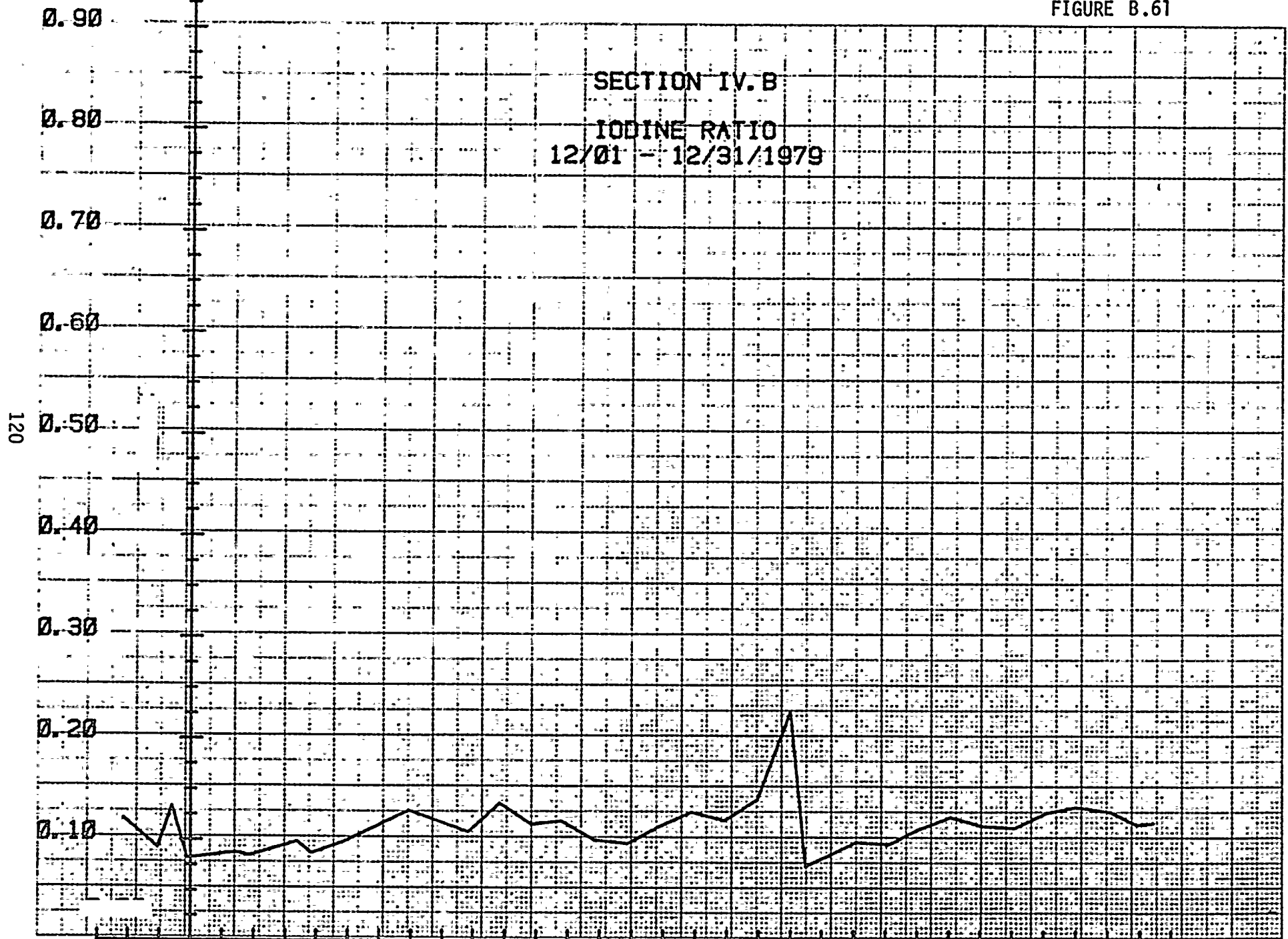


FIGURE B.61



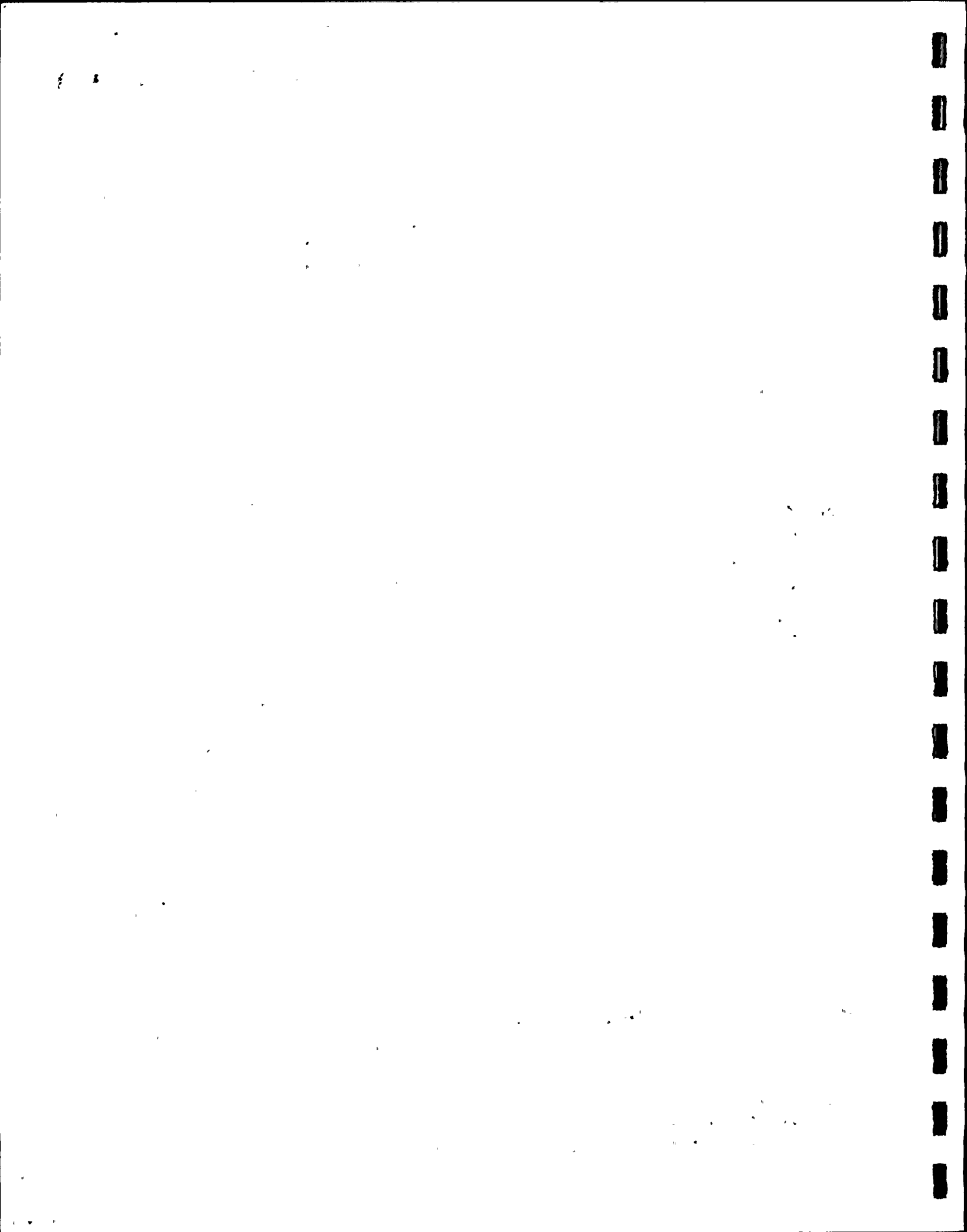


FIGURE B.62

SECTION IV. B

IODINE RATIO

01/01 - 01/31/1980

121

0.90

0.80

0.70

0.60

0.50

0.40

0.30

0.20

0.10

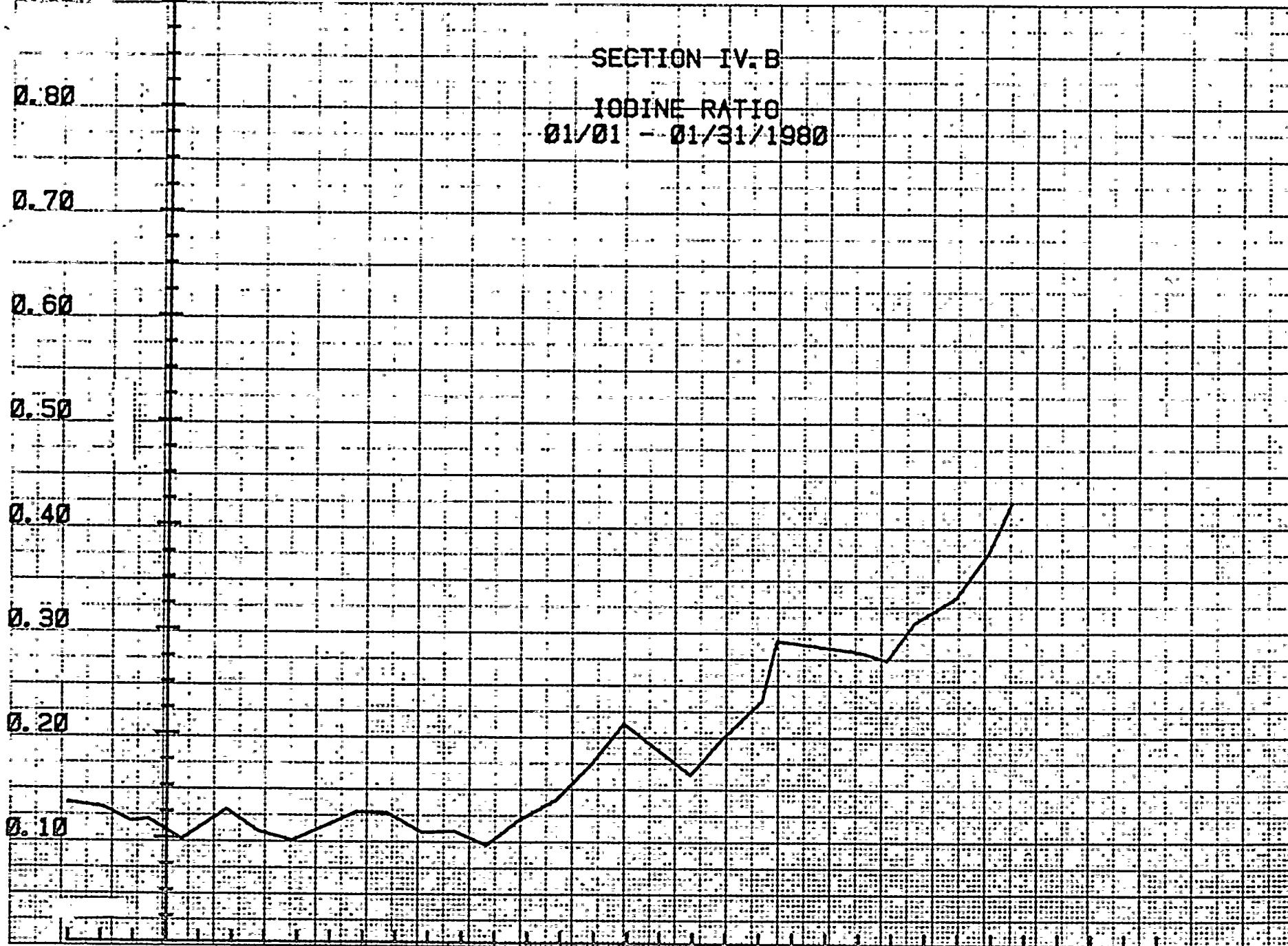
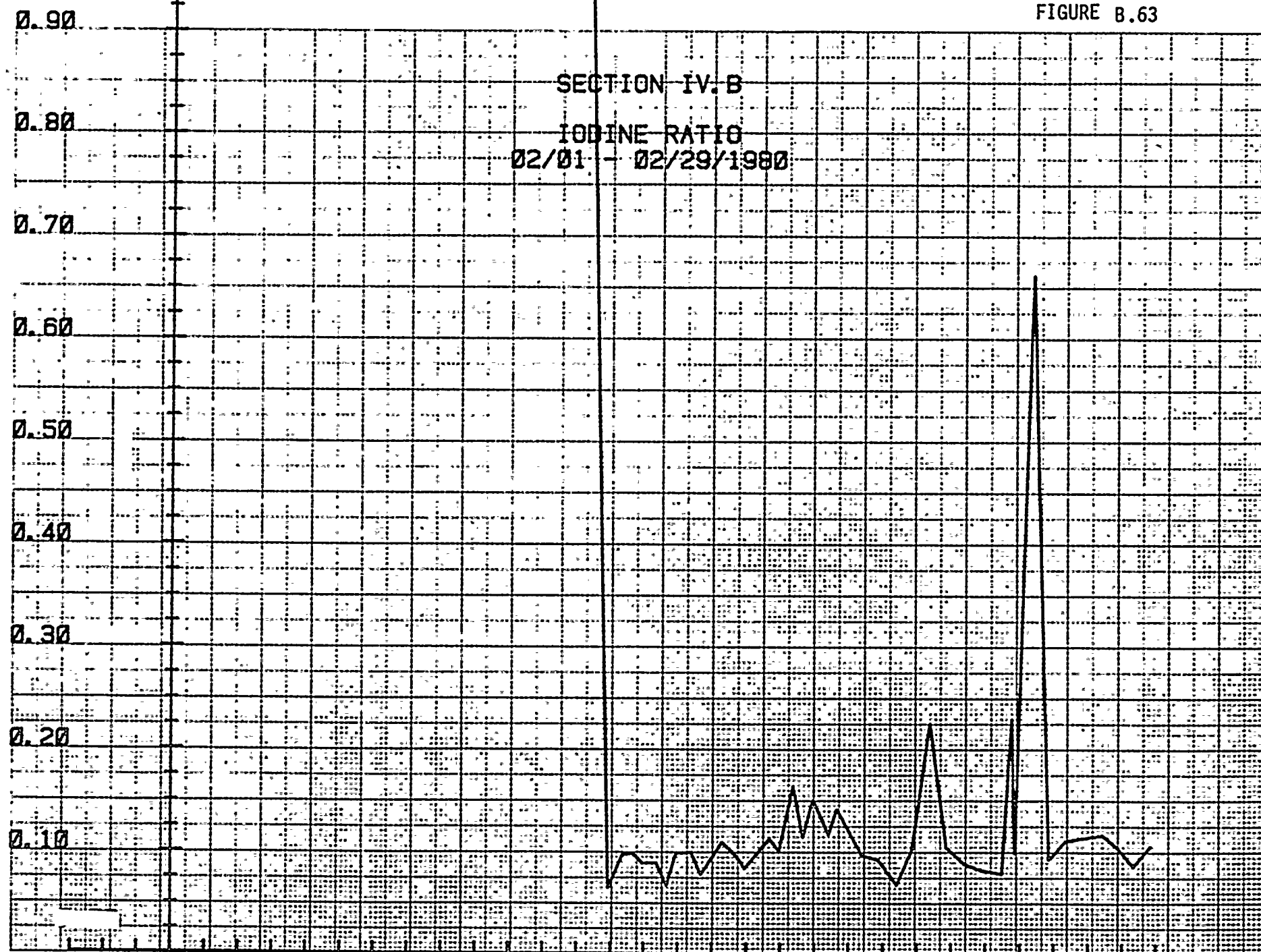


FIGURE B.63

SECTION IV.B
IODINE RATIO
02/01 - 02/29/1980



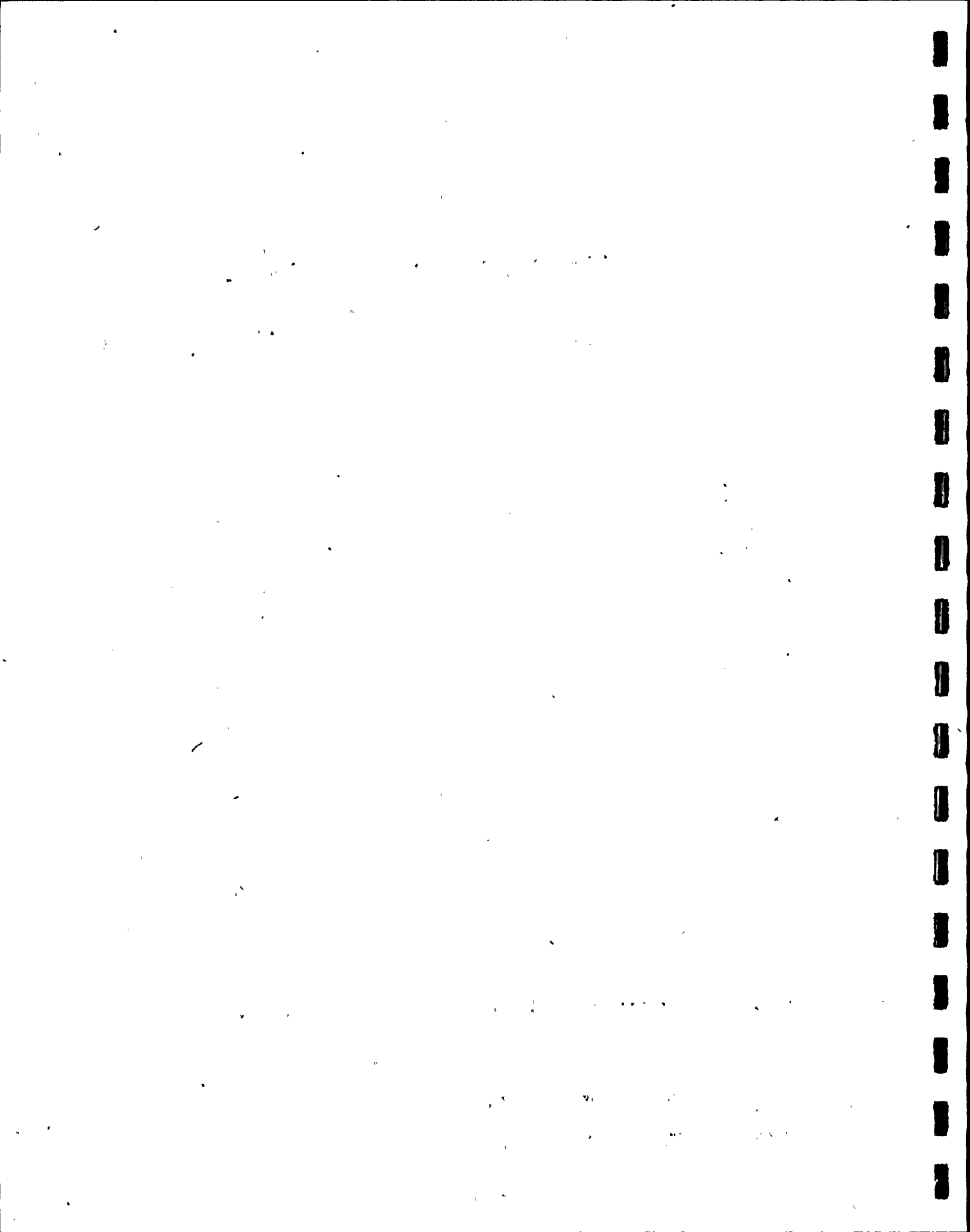
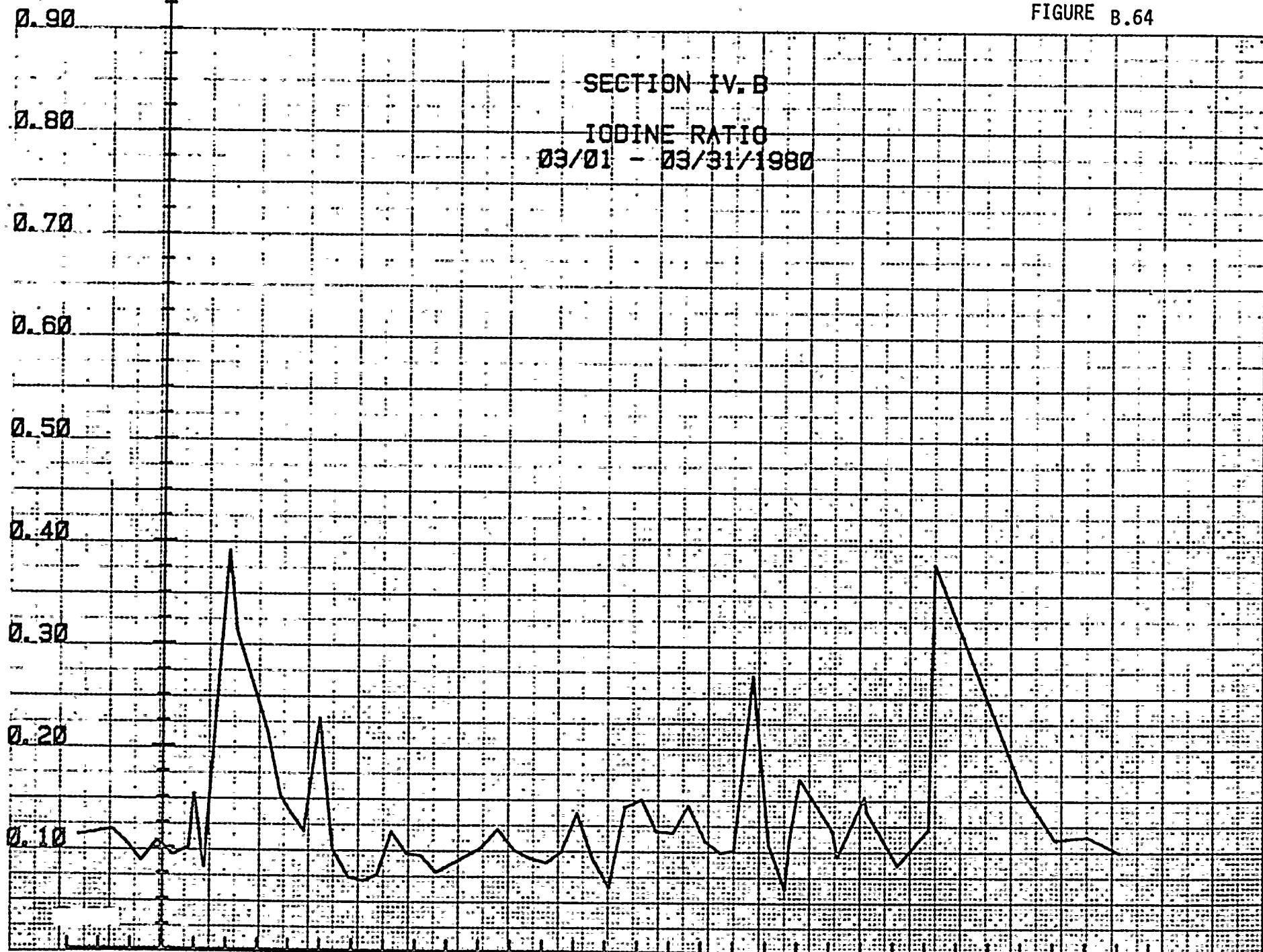


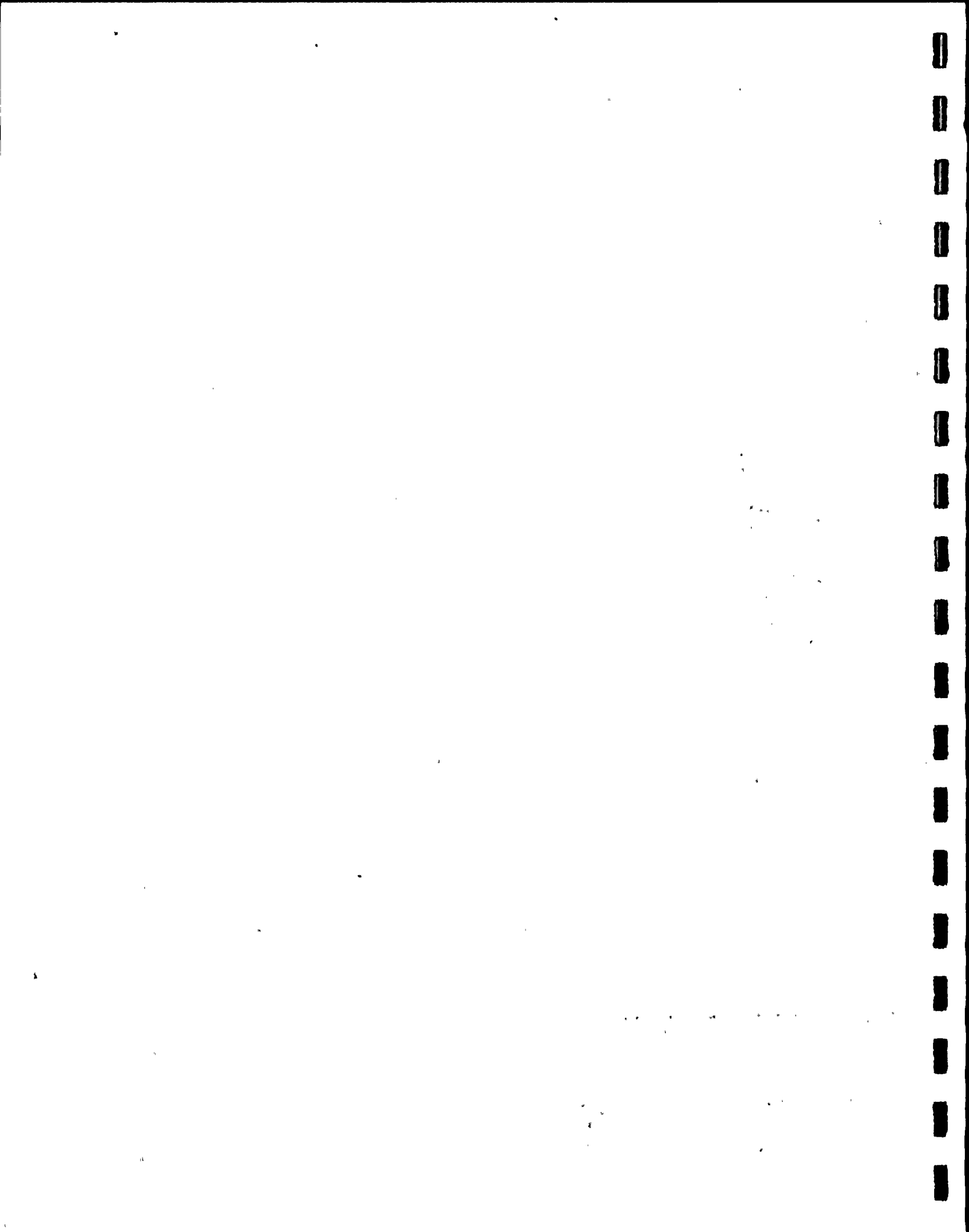
FIGURE B.64

SECTION IV. B

IODINE RATIO

03/01 - 03/31/1980



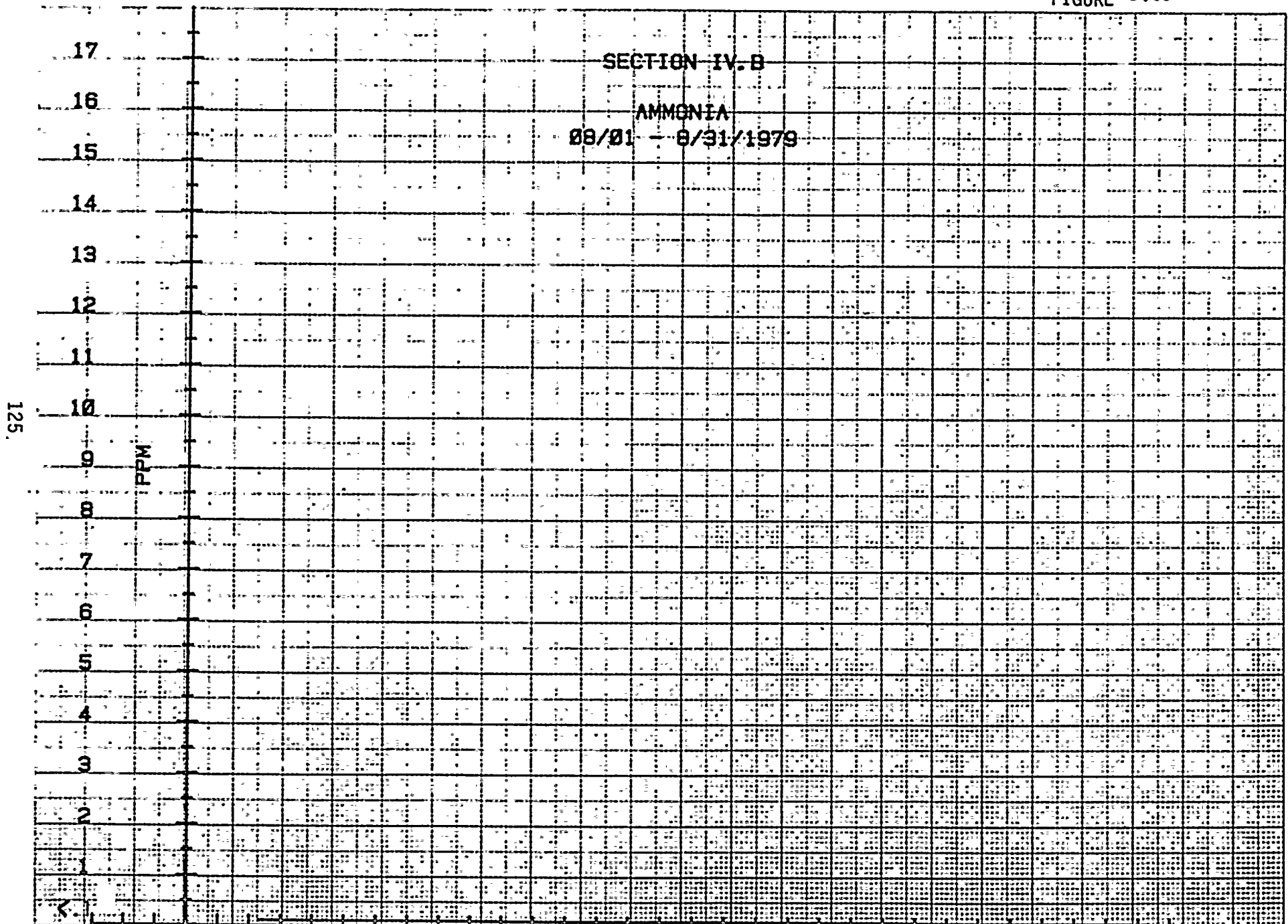


h. Ammonia (Figures B.65-72)

Examination of data regarding RCS ammonia concentration generates the following observations:

- (1) Prior to the injection of hydrazine to the CVCS via RCS makeup water, the RCS ammonia concentration was maintained to within the CE recommended level of 500 ppb (Table IV.A.1). Nominal values were ≤ 100 ppb.
- (2) Subsequent to the hydrazine injections, RCS ammonia concentrations were a function of the injection levels and ion exchanger media condition. Those instances of excessive RCS ammonia concentrations were a result of increased hydrazine injection concentrations (i.e. January 10, 1980, 14 ppm).

FIGURE B.65



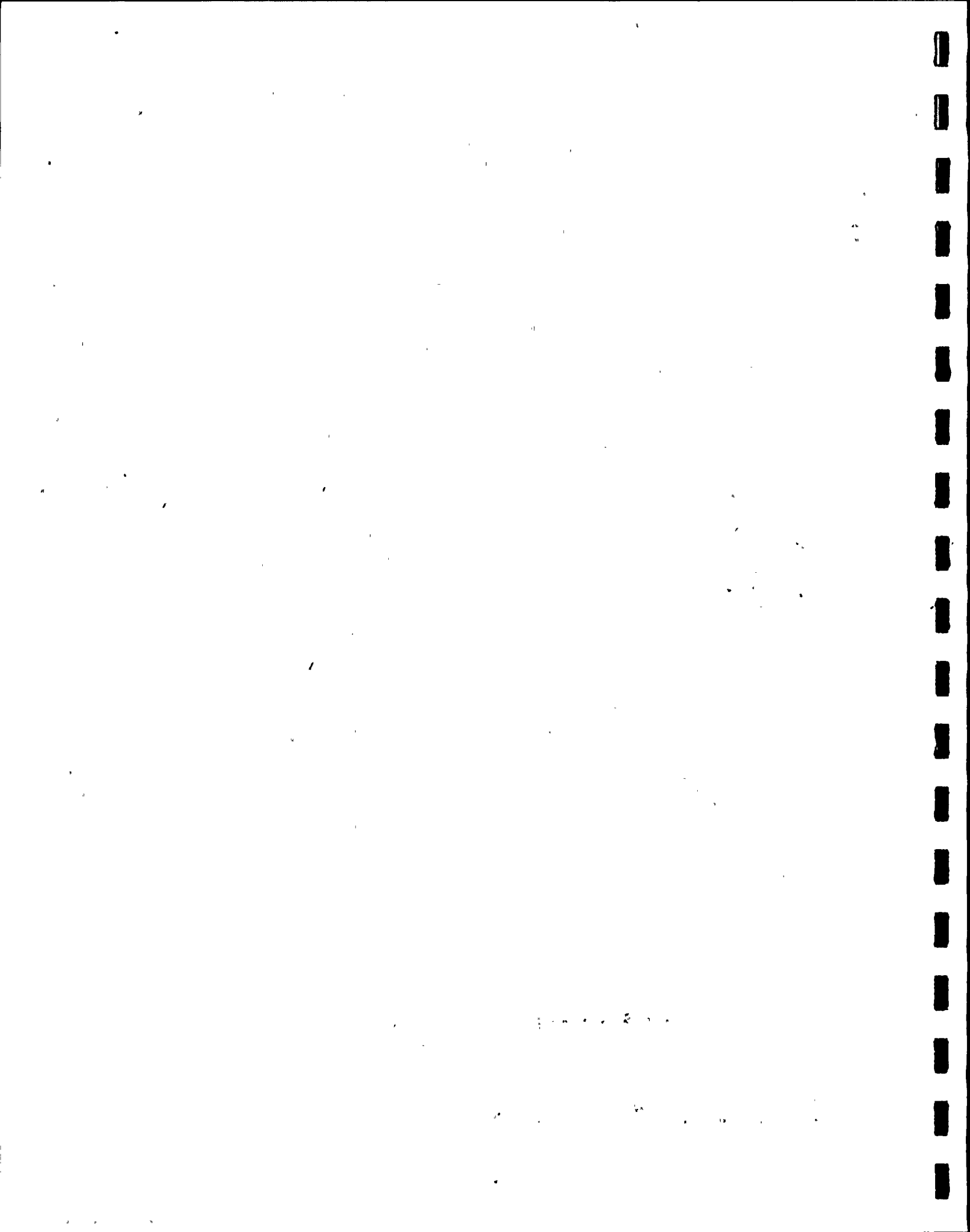


FIGURE B.66

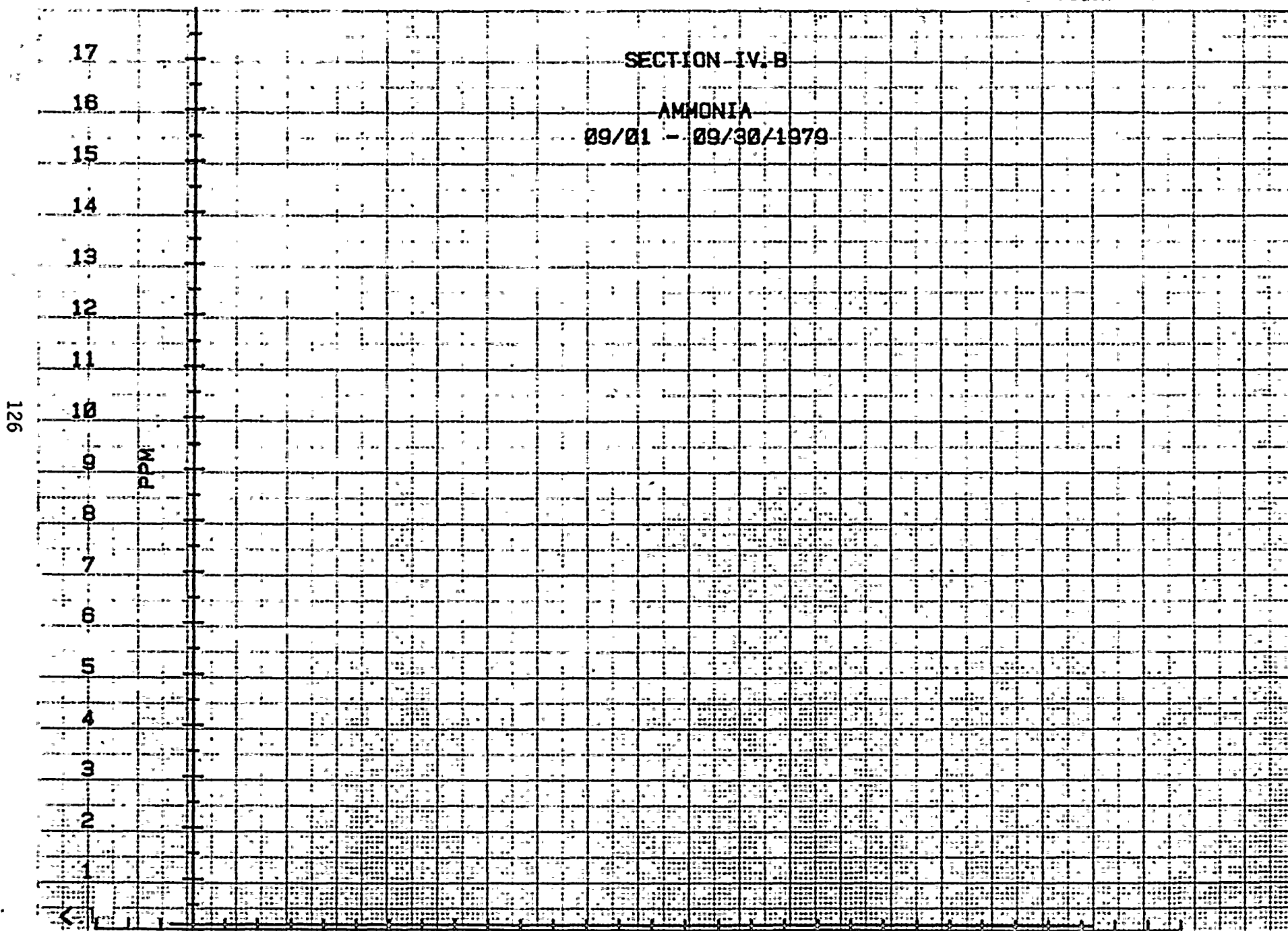


FIGURE B.67

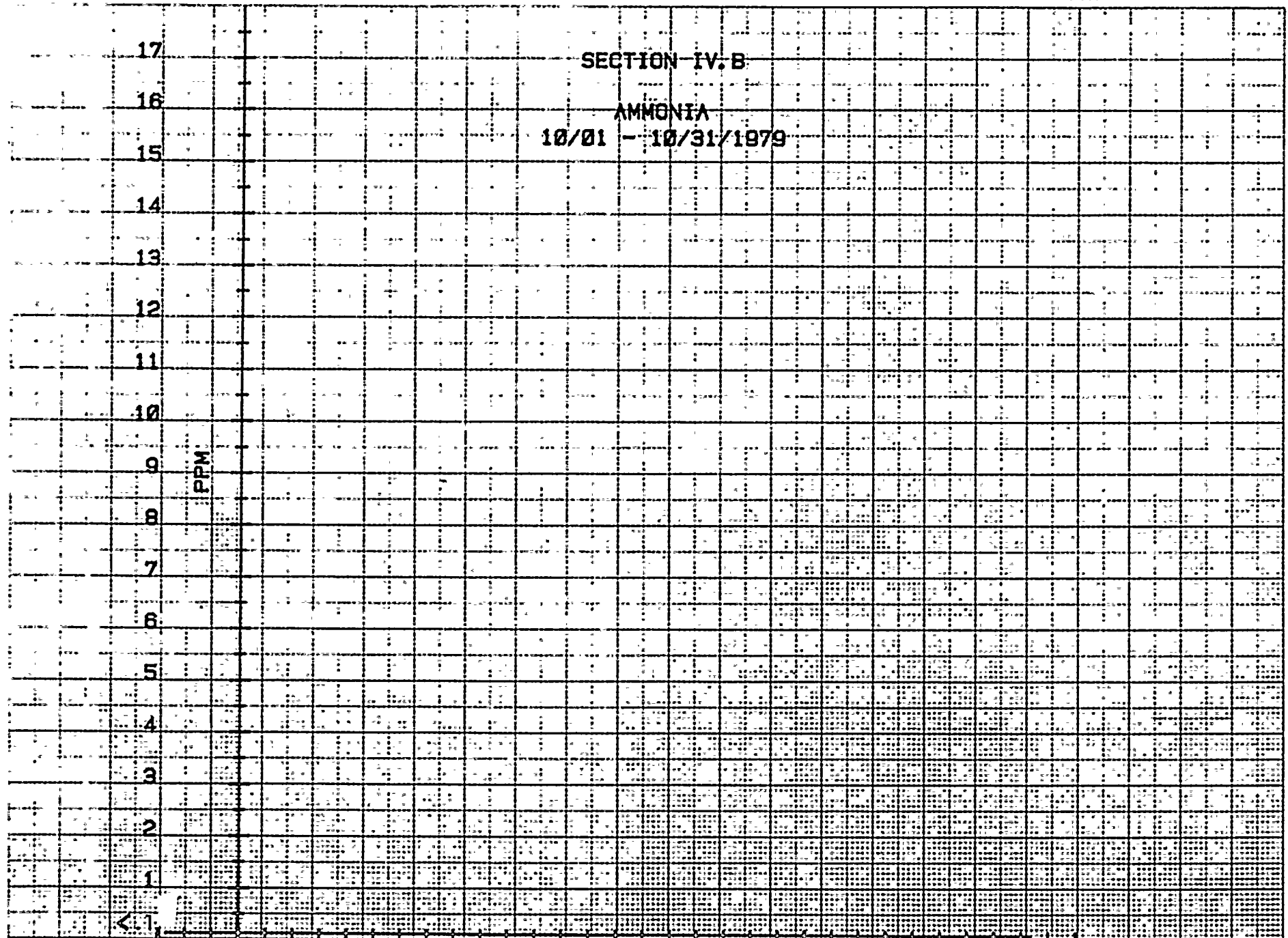
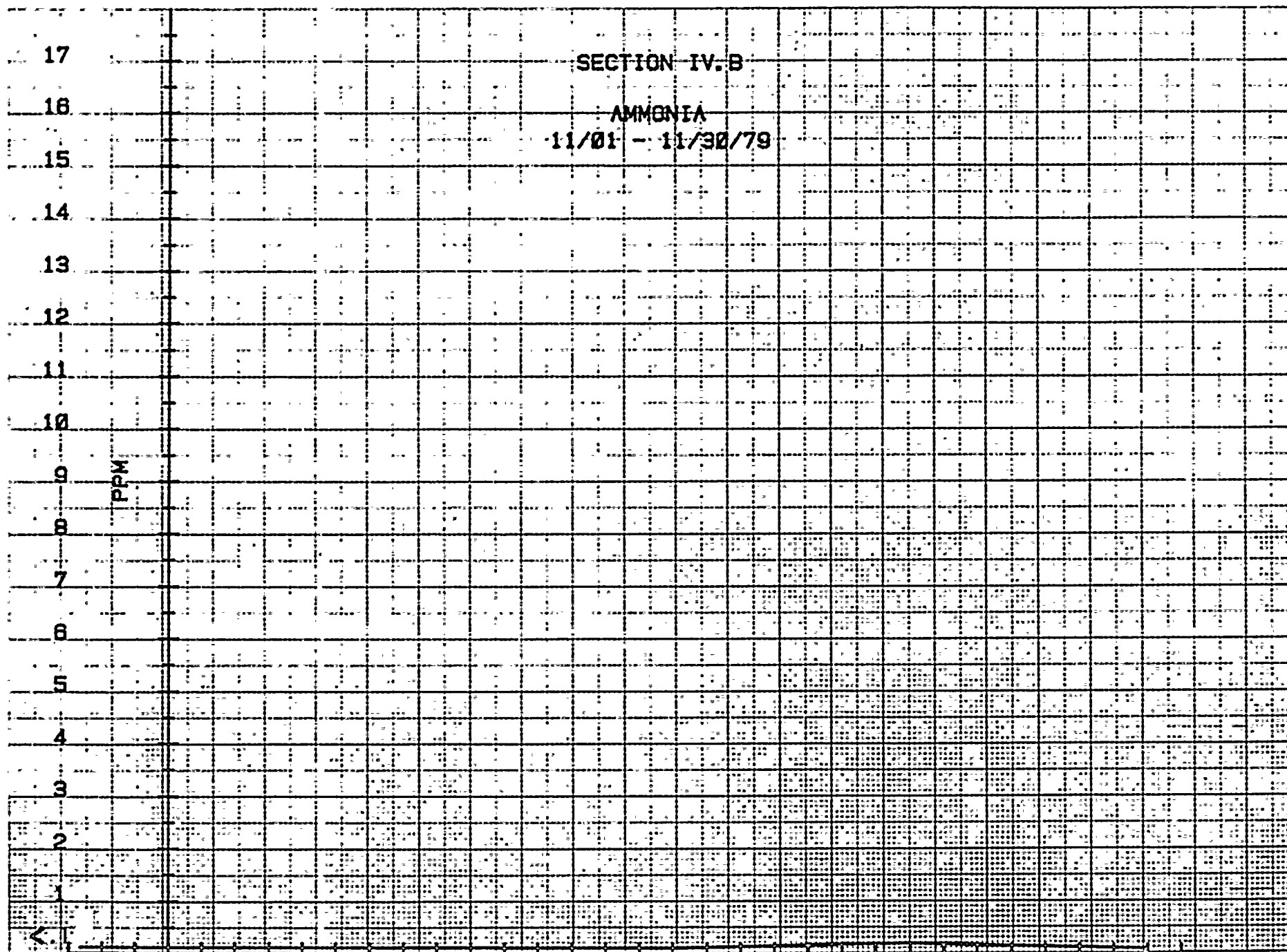


FIGURE B.68



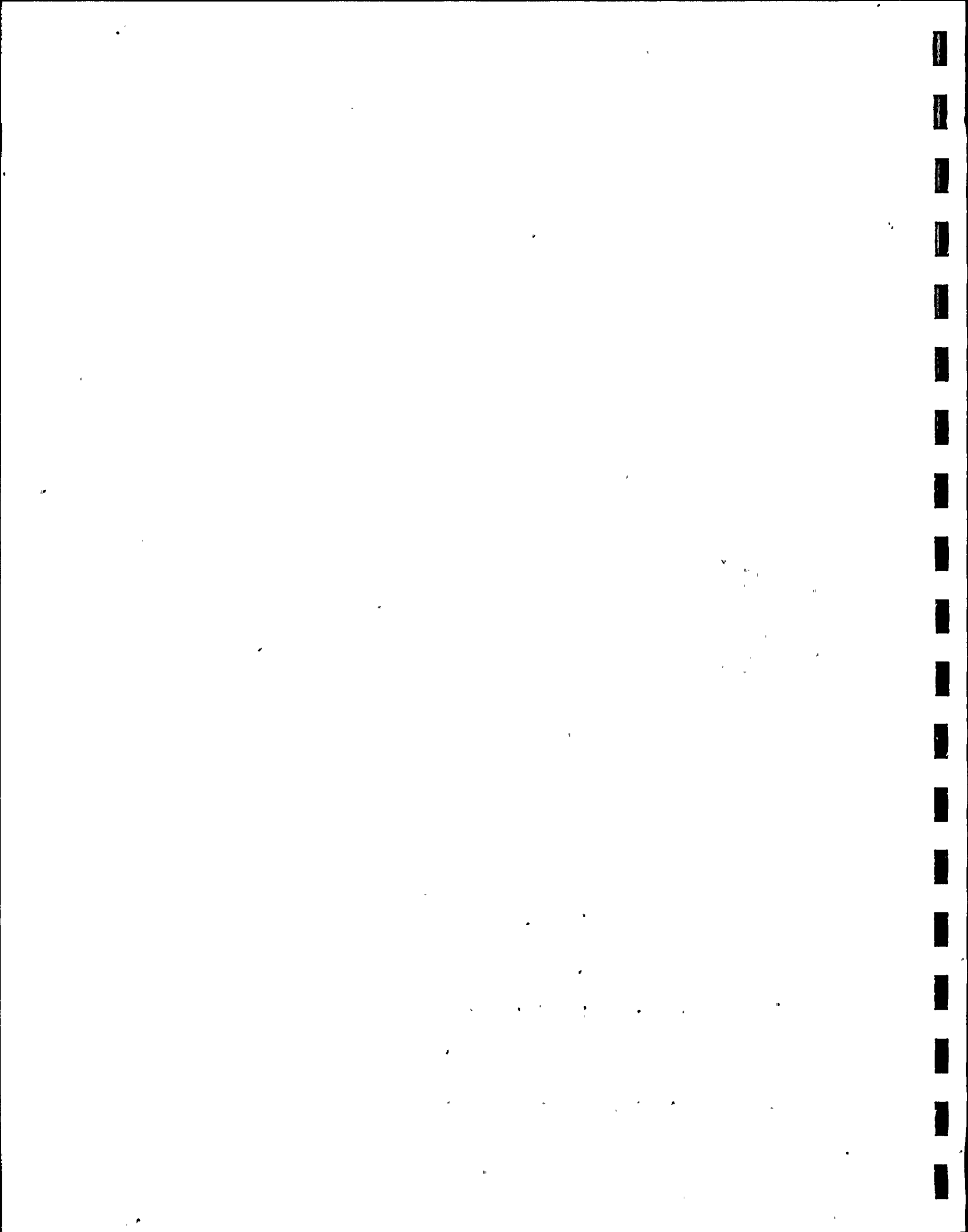


FIGURE 8.69

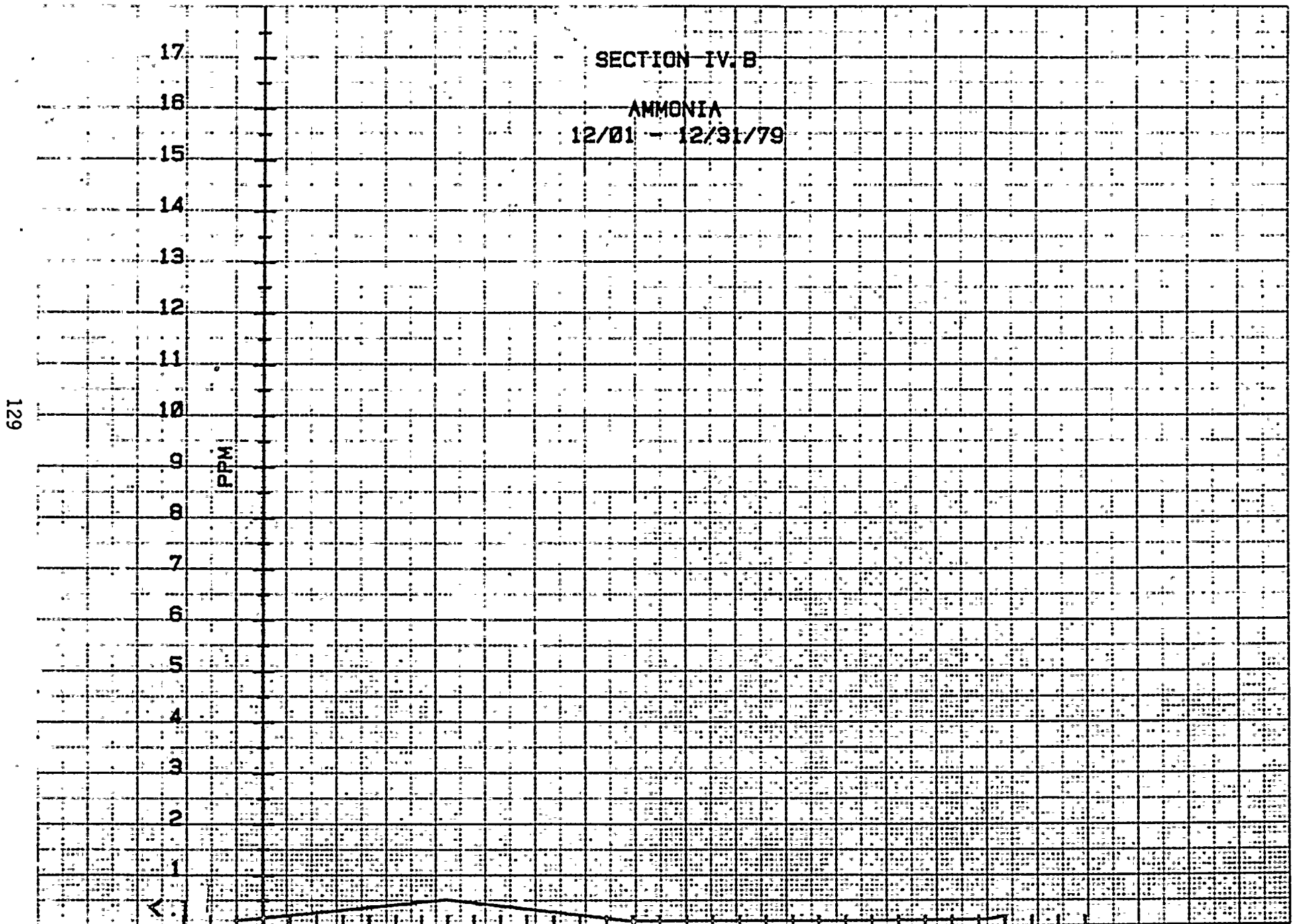


FIGURE B.70

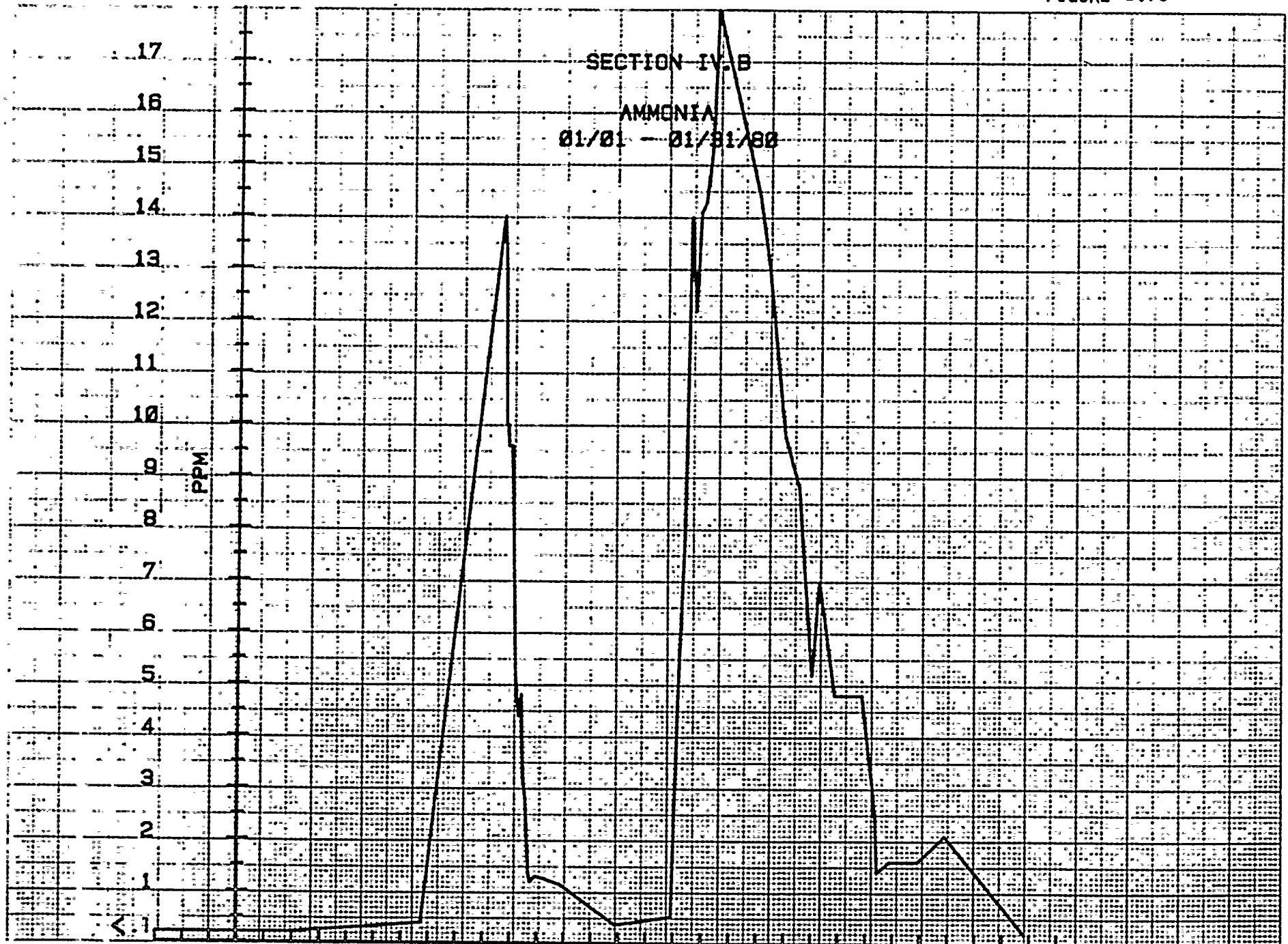
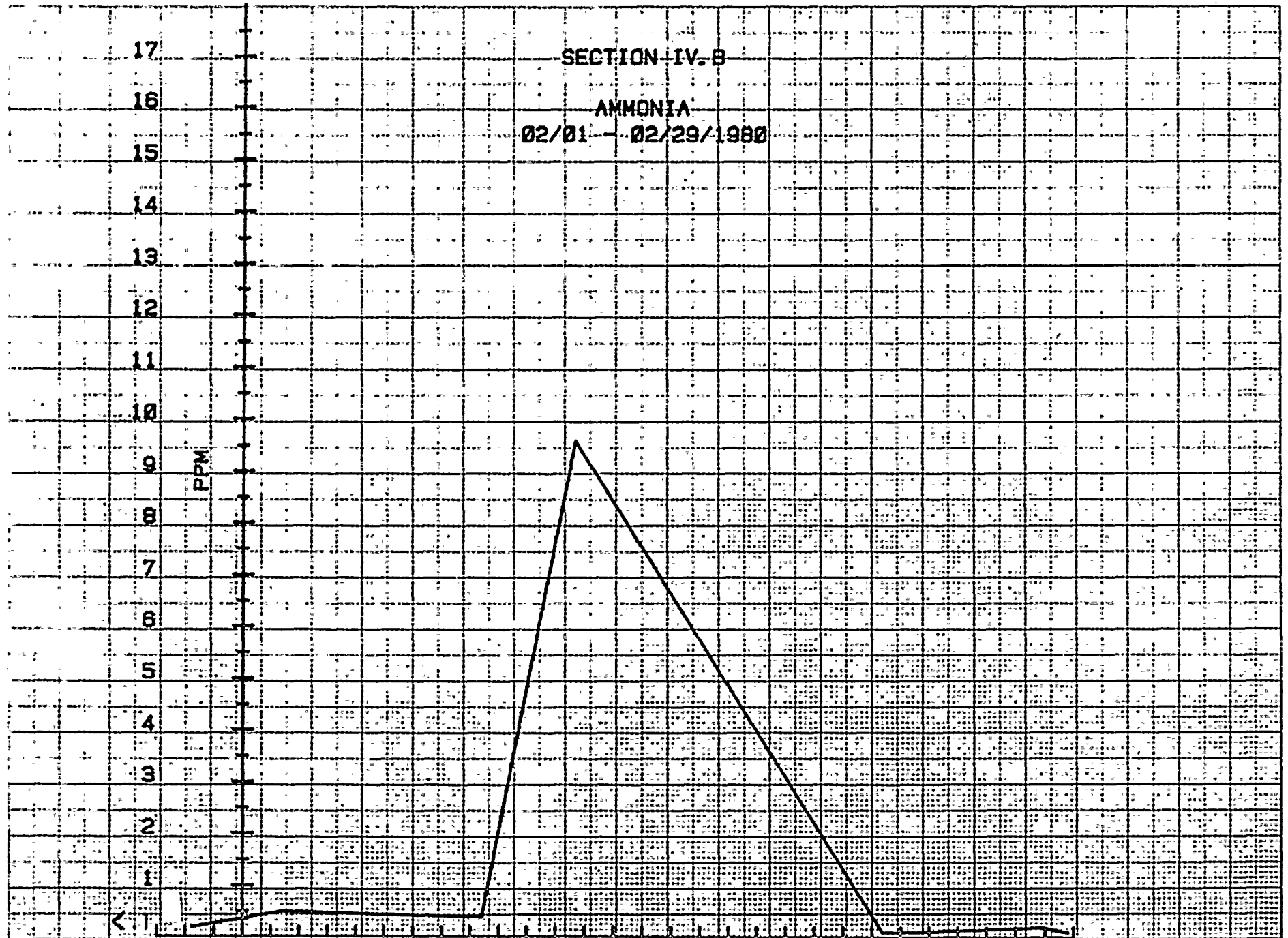


FIGURE B.71



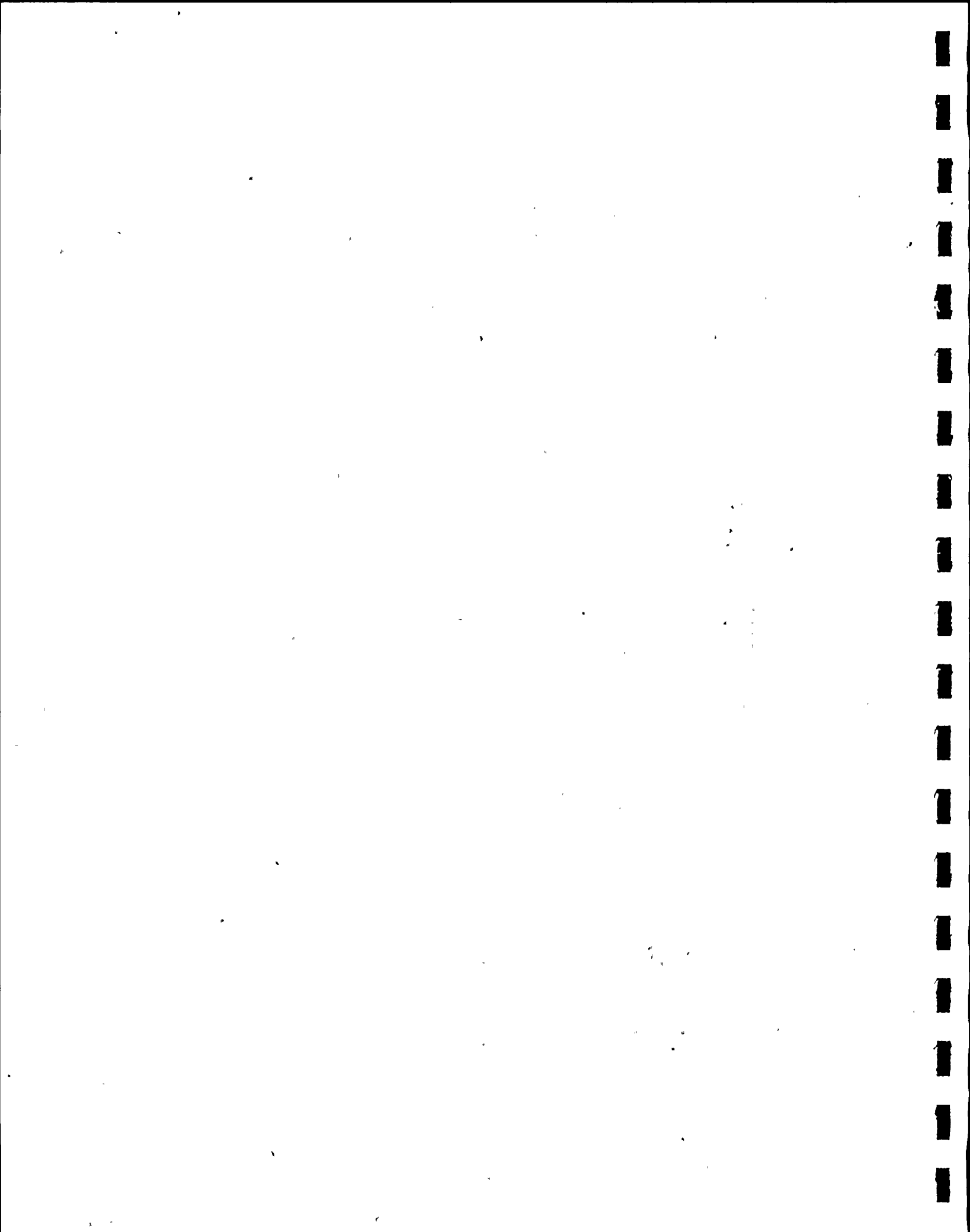


FIGURE B.72

SECTION IV.B

AMMONIA

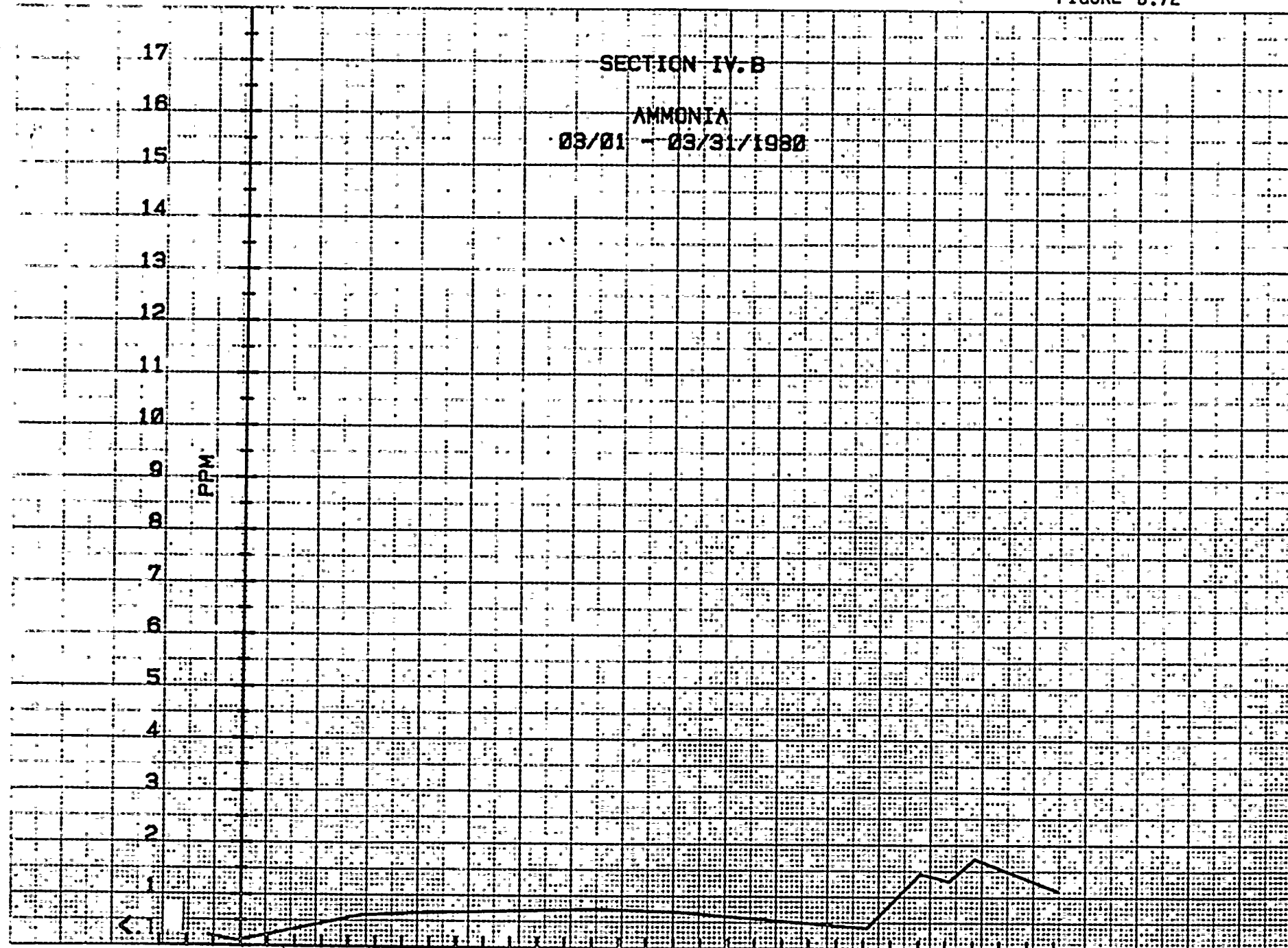
03/01 - 03/31/1980

PPM

17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1

<1

132

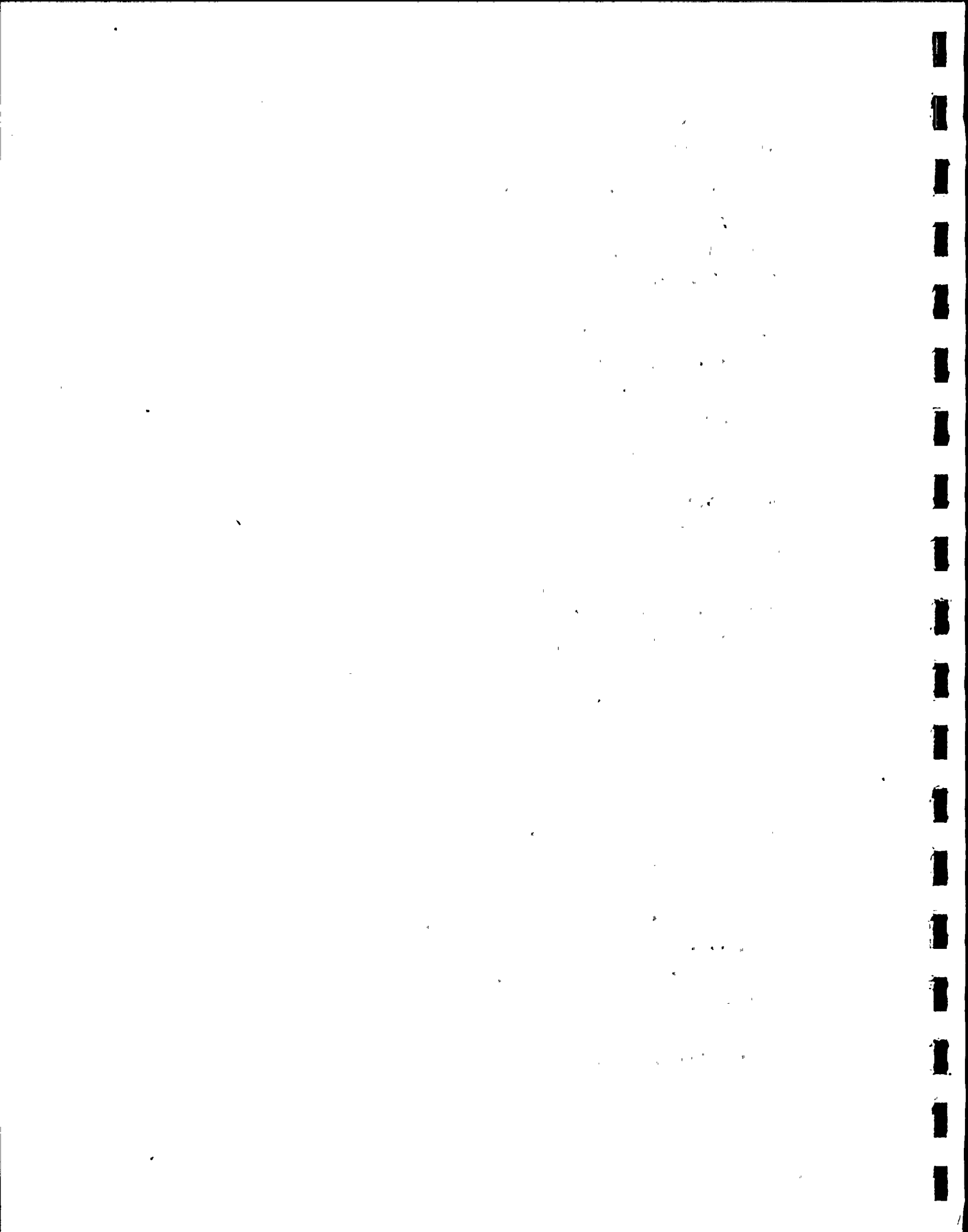


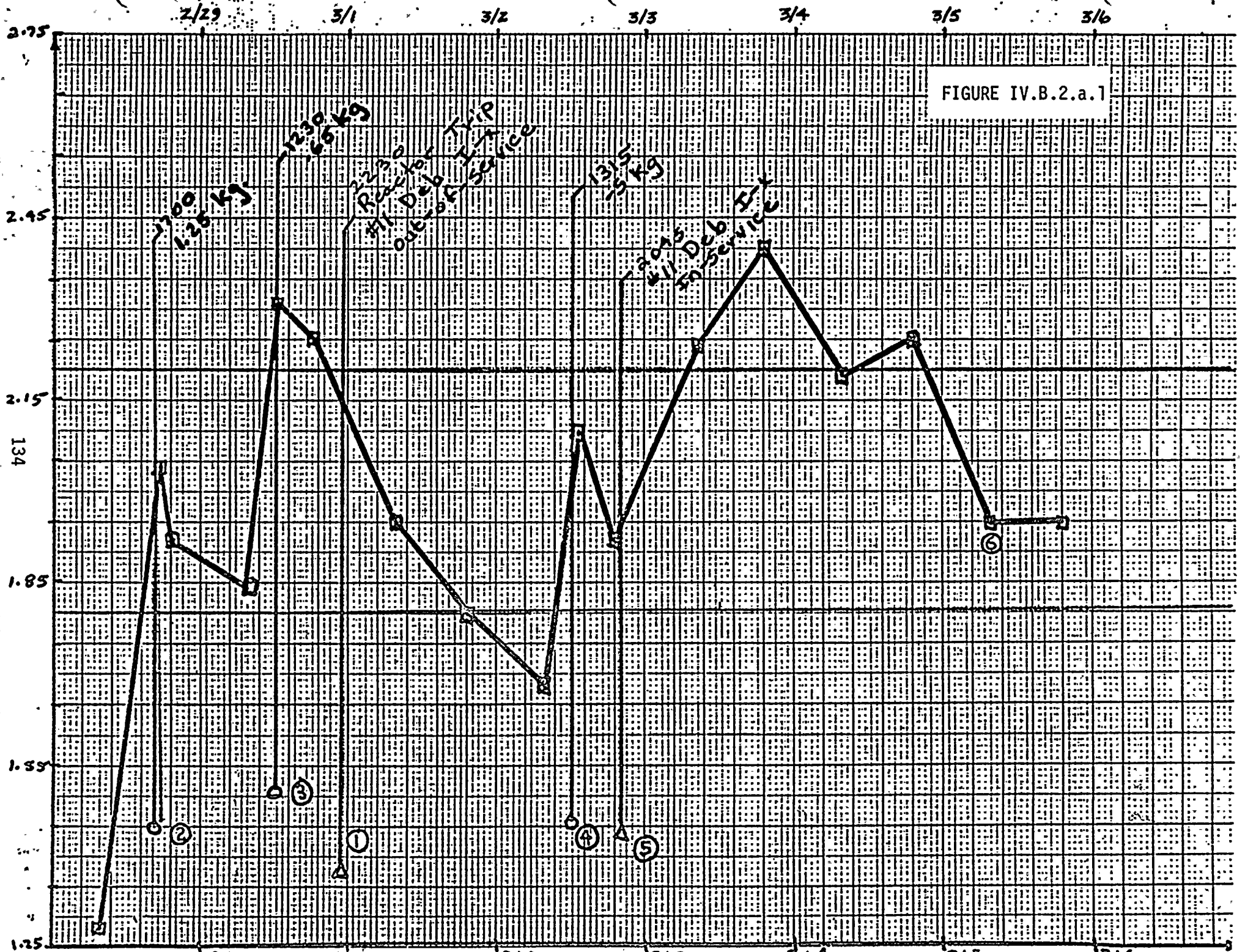


2. Evaluations and Actions

a. Reactor Coolant System Lithium Concentration

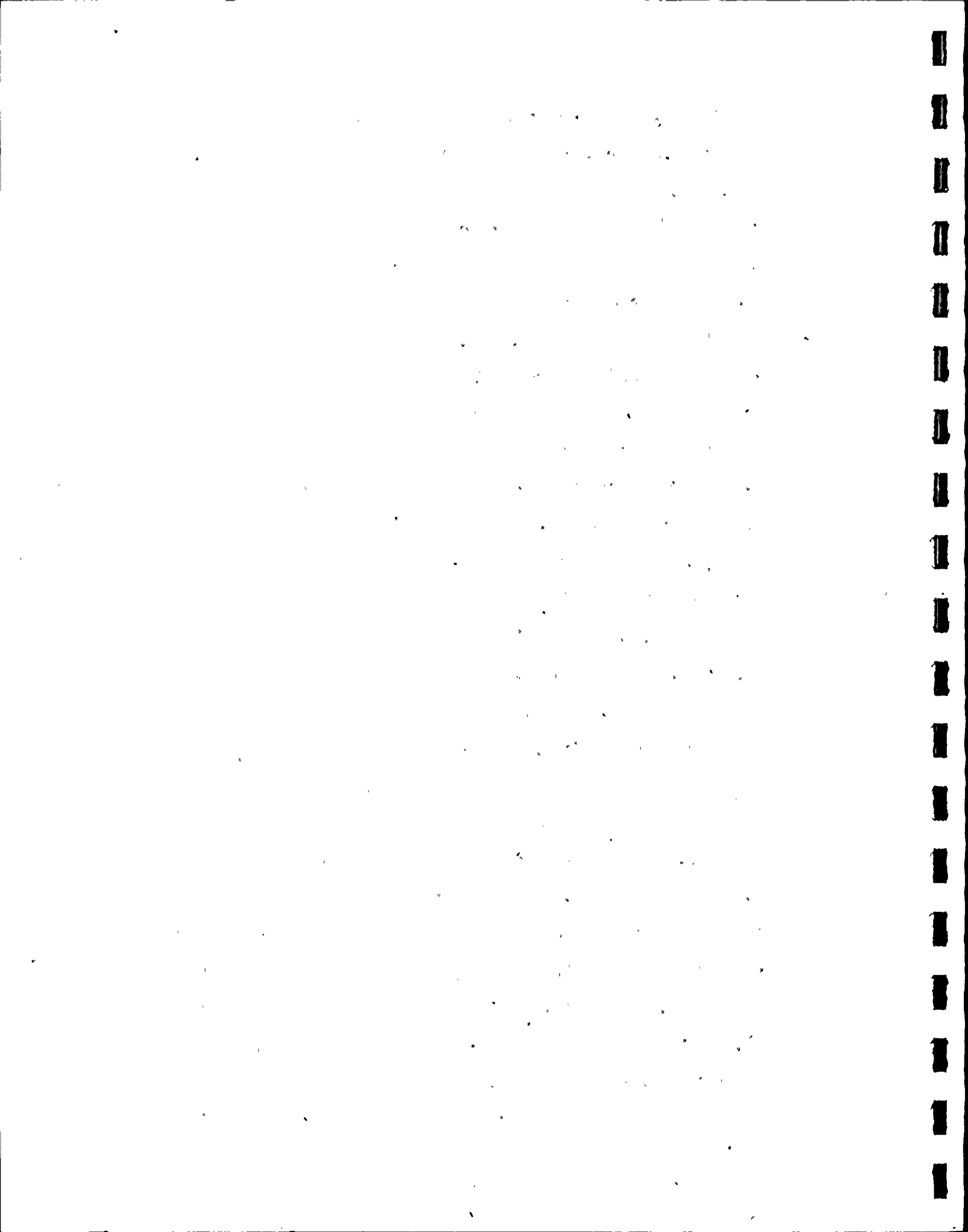
As discussed previously, RCS lithium concentration is normally maintained at less than 1.0 ppm. As a result of unexpected increases on axial shape index, radial peaking factors, reactor vessel differential pressure and abnormal power distributions, on 11/08/79 CE recommended that RCS lithium concentration be increased to a maximum of 2.2 ppm (Reference 6). The reason for the recommendation was to increase crud solubility in an attempt to transfer it from core surfaces. As evidenced from examination of the lithium plots, plant staff implemented the recommendation as part of near term corrective action. Lithium concentration in the RCS remained at the prescribed level until CE's recommendation of 03/07/80 to reduce the chemical parameters to original specifications (Reference 7). It should be noted that on several occasions RCS lithium concentrations drifted slightly above the lithium concentration guideline. These deviations were caused by normal chemistry control problems associated with plant operation and were not considered significant. For instance, on 03/01/80, an aberrant episode in lithium concentration occurred (Reference 8) over a three day period. The maximum lithium concentration observed was 2.4 ppm at 2000 hrs. on 03/04/80 for a period of less than 10 hours. The nominal lithium range of (1.8-2.2) was exceeded for approximately 30 hours. The apparent cause of the perturbation was the removal of an ion exchanger from service following a planned power transient. Lithium hydroxide monohydrate ($\text{LiOH} \cdot \text{H}_2\text{O}$) additions to the RCS were not coordinated with the purification system lineup. As a result, observed lithium concentrations was in excess of anticipated values. Investigation into the cause of the anomaly resulted in the ion exchanger being placed in service with subsequent RCS lithium concentration reduced to within the nominal operating band. The incident is displayed in detail in Figure IV.B.2.a.1. No significant effects on the power anomaly were observed due to the minor excursions from normal lithium concentrations experienced during this and associated incidents.





b. Hydrazine Addition to Reactor Coolant System

Based on a concern for potential air ingress into the RCS on 12/11/79, CE recommended that hydrazine be added to the VCT in quantities which were based on analysis of oxygen in the makeup water (Reference 9). After an evaluation of the recommendation to insure that there would be no effect on overall RCS chemistry, plant staff initiated continuous injection of hydrazine to the RC makeup pump discharge during normal operation. The hydrazine was injected at a rate and concentration that would provide an excess of hydrazine to the RCS. Plant staff was concerned that hydrazine additions would significantly increase RCS ammonia concentrations. Examination of Figures B.65 through B.72 illustrates that baseline ammonia level in the RCS increased when hydrazine was injected into the makeup water. On several occasions, excessive levels of hydrazine in the RC makeup resulted in significant increases in RCS ammonia and conductivity levels. The initial incident occurred on 1/10/80 and was accompanied by a rapid decrease in core differential pressure. The event was caused by the inadvertent addition of 15 gallons of 35 wt% hydrazine to the chemical addition metering tank. Hydrazine injection to the RCS makeup occurred from 2000 on 1/9/80 to 0730 on 1/10/80, when the injection was terminated and an investigation conducted. Sampling at the charging pump discharge showed a hydrazine level of 3.2 ppm compared to a nominal value of approximately 300 ppb. The excessive ammonia level which resulted from hydrazine decomposition caused release of lithium from the in-service ion exchanger due to an upset in the equilibrium concentration.



Lithium increased to approximately 3.8 ppm as a direct result of this incident (Reference 10). It was postulated by CE that the cause of the core differential pressure drop was due to the ammonia forcing lithium from the resin bed. The sudden high lithium concentration caused crud removal from the core. Subsequent hydrazine levels outside the nominal band have been observed in the CVCS as a result of operational difficulties with the temporary injection system.



c. Oxygen Ingress to Reactor Coolant System

As a result of concerns regarding the introduction of air into the RCS via the RC makeup water the following modifications to chemistry procedures were initiated:

- (1) VCT hydrogen addition rates were recorded and monitored to determine if consumption was excessive and samples were taken to establish a baseline for oxygen entering the RCS through the purification system under normal conditions.
- (2) Initial quantification of oxygen ingress was accomplished by performing daily oxygen analysis downstream of the charging pumps. These analyses were performed at the following conditions during normal power operations:
 - (a) Just prior to adding makeup to the VCT; at the low extreme of the normal operating band.
 - (b) Within 15-30 minutes after adding makeup to the VCT; at the high extreme of the normal operating band.
- (3) If oxygen at the charging pump discharge was measured at greater than 5 ppb, samples were taken at the following locations to determine possible sources of air ingress:
 - (a) Charging pump suction
 - (b) Volume control tank (VCT)
 - (c) Reactor (primary) water storage tank
 - (d) Letdown system ion exchanger inlet and outlet



In addition, the following modifications to operating procedures and hardware were made to prevent oxygen ingress from the resin transfer system to minimize air ingress from the RC makeup water and to increase solubility of crud in the RCS.

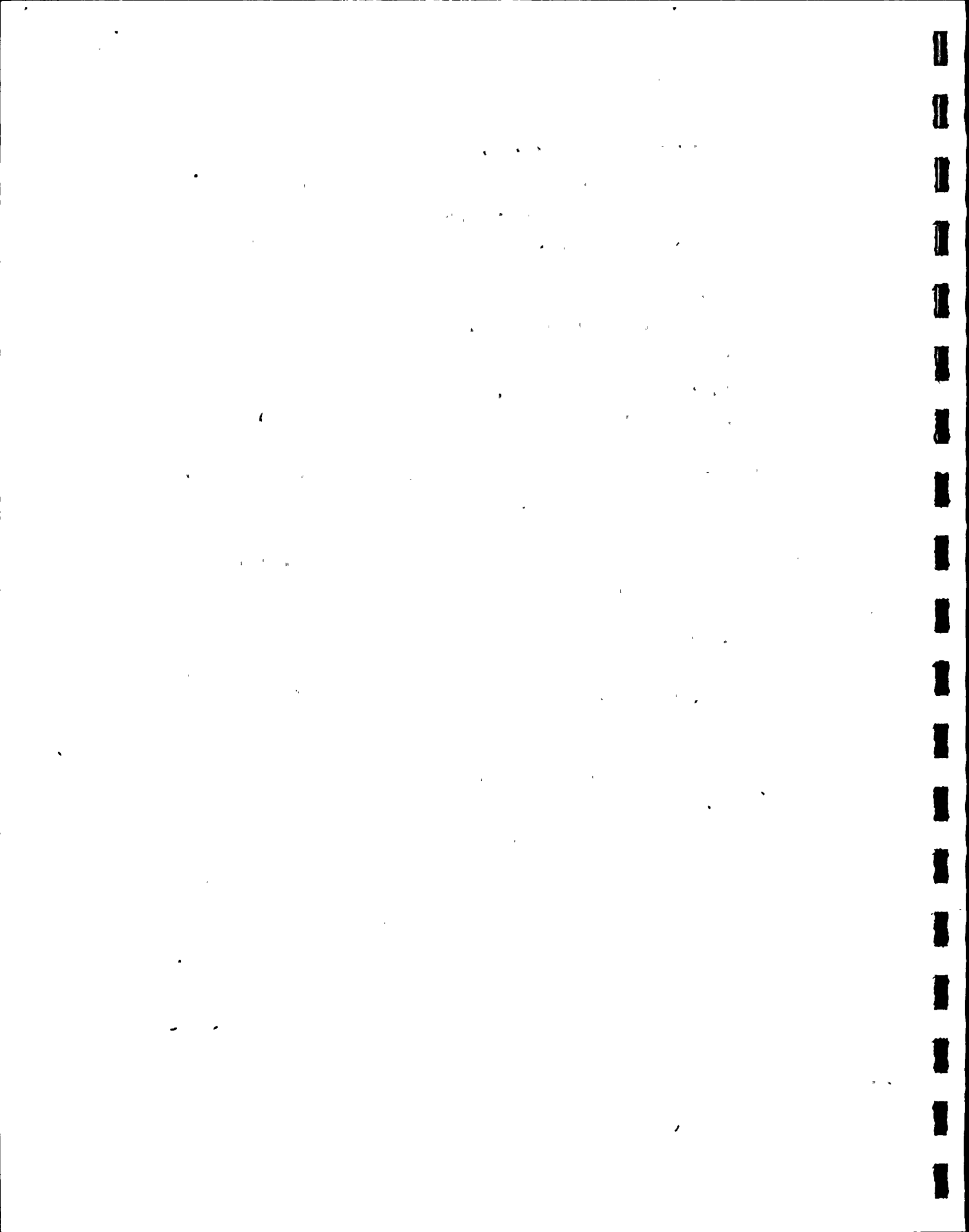
- (1) Hydrazine leaving the VCT was controlled to stoichiometric quantities based on analysis of O_2 in the makeup water entering the VCT.
- (2) Hydrogen overpressure in the VCT was increased to a level sufficient to increase H_2 dissolved in the RCS to 40 cc/kg.
- (3) Nitrogen instead of air was used to transfer resin.
- (4) Two leaking valves in the resin transfer system were repaired.
- (5) The leaking power operated relief valve was repaired.

Evaluation of Figures B.41 through B.48 describing oxygen levels in the RCS and VCT reveals that the combined corrective action recommended by CE (References 12, 13) and implemented by plant staff was effective in minimizing oxygen ingress.

d. Hydrogen Peroxide Treatment

The hydrogen peroxide treatment, initiated on January 27, 1980, was very successful in returning core differential pressure back to pre-episode levels. A complete and detailed documentation of the chemistry and radiochemistry aspects of the addition is contained in Appendix A. The following is a summary of the results of the hydrogen peroxide treatment:

1. The hydrogen peroxide chemical treatment combined with the plant cold down/heat up temperature shock reduced core differential pressure from 15.6 psi to the pre-episode value of 13.8 psi.
2. A total volume of 15.1 liters of hydrogen peroxide was added to the RCS in three separate injections.
3. Increases in total Co-58 activity and suspended solids indicated the hydrogen peroxide treatment produced a significant crud release.
4. Based on a comparison of data collected here with the results of an EPRI study, reactor core deposits appear to be the major source of activity released.
5. Approximately 600 Curies of Co-58 was removed from the coolant during and following the hydrogen peroxide treatment.
6. Hydrogen peroxide additions did not cause unexpected changes in shutdown radiation fields.



e. Reactor Coolant System Crud Samples

As part of the assessment of the power distribution episode, two samples of circulating crud were taken from the reactor coolant and submitted to CE's Nuclear Laboratory for analyses. The following is a summary of analyses performed and results obtained:

Sample #1 was taken on December 6, 1979 near the peak of the core physics anomaly, with the plant at 70% power. It was hoped that the sample would provide clues as to the cause of the anomaly.

Sample #2 was taken on January 28, 1980; with the plant at cold shutdown, during a crud burst generated by the addition of hydrogen peroxide. This sample was taken to satisfy an NRC request for information on the composition of crud released due to hydrogen peroxide.

The following analyses were performed on the samples:

- . visual examination and (for Sample #2) drying and weighing
- . mounting for X-Ray fluorescence
- . γ - spectroscopy (for Sample #1)
- . X-Ray fluorescence to determine elemental composition
(atomic number 12 - magnesium)
- . X-Ray diffraction to determine crystalline compounds for (Sample #1)
- . digestion in oxidizing acids to provide liquid solution for
atomic absorption and emission spectroscopy
- . elemental analyses by atomic absorption
 - Sample #1: Li, Be, Na, Mg, Ca
 - Sample #2: Li, Na, Mg, Ca, Cr, Fe, Ni
- . emission spectroscopy for boron

Sample #1 was found to be nickel-rich, with a substantial concentration of nickel metal. The reactor coolant system had apparently been chemically reducing at the time the sample was taken. The overall composition was consistent with corrosion product release expected from the major system materials. Most of the material originally came from the steam generator tubing (Inconel-600). The immediate source of the crud (in-core or out-of-core surfaces) could not be established. Nothing was found which could be related to the anomaly.

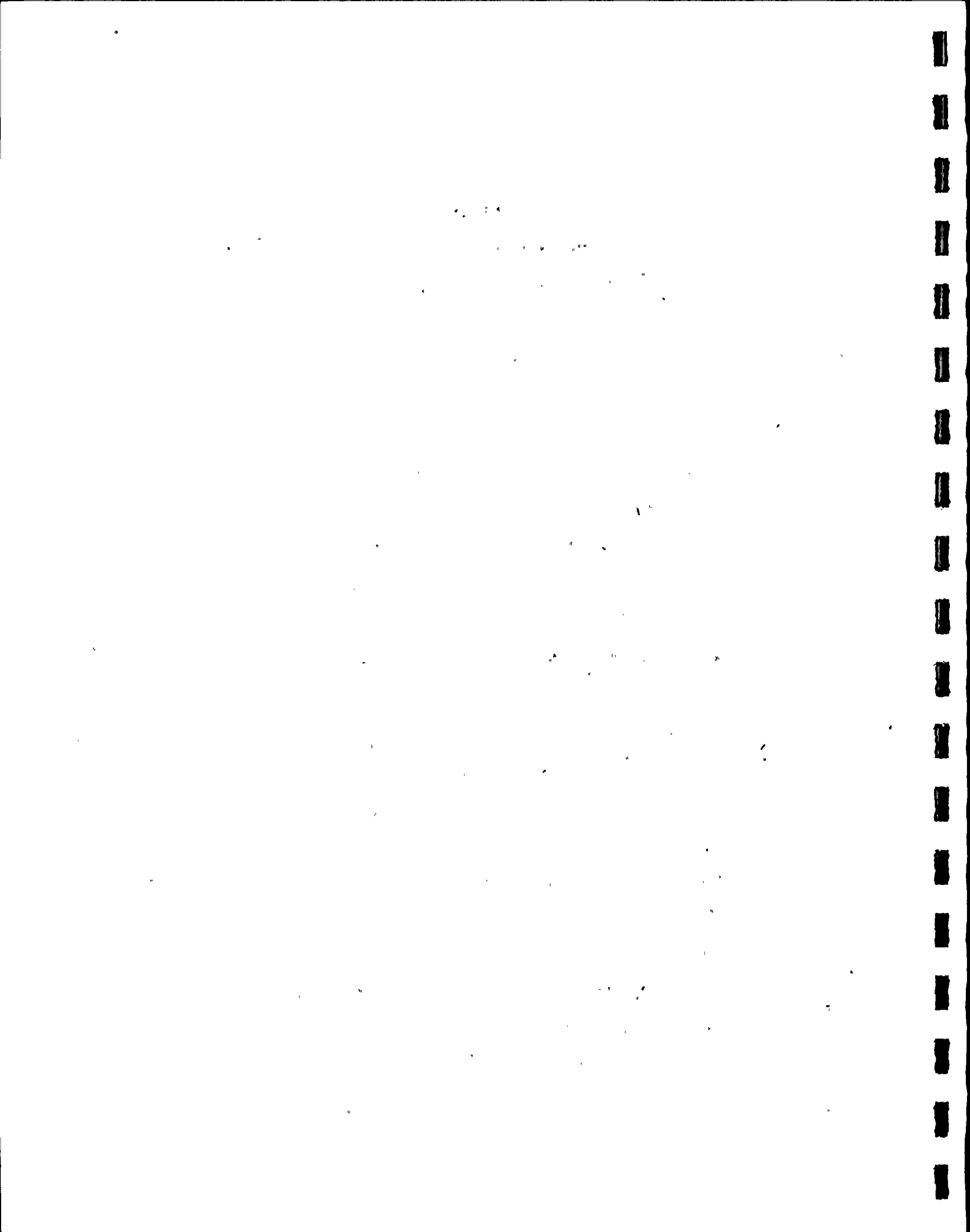
Sample #2 contained iron and nickel in about equal proportions. This composition was consistent with observations that peroxide additions favor the dissolution of nickel relative to iron oxides. The crud appeared to have been released from core surfaces.

Nothing was found in either sample which would raise concerns relative to accelerated corrosion of fuel cladding due to the deposition of these materials.

f. Modification to Chemistry Surveillance Program

During the power distrubtion episode, periodic adjustments in the chemistry surveillance program were implemented. For the most part, these changes were prompted by recommendations from CE followed by evaluation by plant staff to assess impact on overall chemistry management prior to implementation. The following modifications to the routine chemistry surveillance program were instituted (Reference 16, 17):

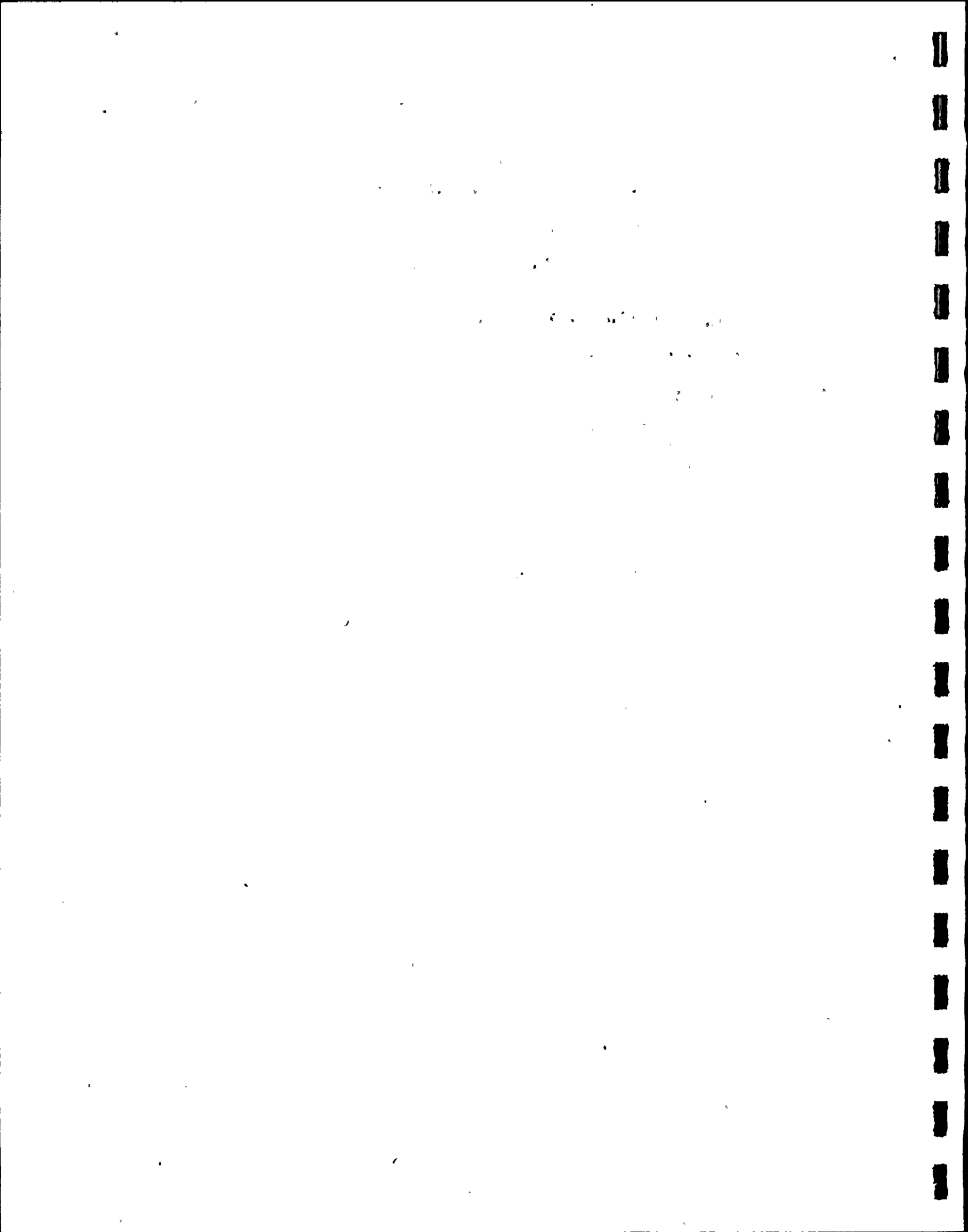
- (1) The following parameters are now analyzed in accordance with the predetermined sampling frequencies and the results recorded in a graphic form in order to reveal any trends that may develop. The parameters of interest are RCS oxygen and hydrogen concentrations, and the Iodine 131/133 ratio.
- (2) Hydrogen inventory requirements in the primary system are recorded/graphed/evaluated. This information is displayed in a graphic form in conjunction with Item (1) above.
- (3) Volume Control Tank (VCT) hydrogen consumption rates are recorded/graphed/reviewed to determine if excessive consumption is taking place.
- (4) A baseline level for oxygen concentration in the effluent of the RCS ion exchanger's under normal operating conditions (steady state power--no abnormal plant evolutions) was established.
- (5) Oxygen ingress into the RCS was quantified by performing an analysis on samples taken at the charging pump discharge. A daily sample must meet one of the following criteria:



- Sample obtained just prior to adding makeup to the VCT.
(Low end of normal operating band).
- Sample obtained within 15-30 minutes after adding makeup
to the VCT. (High end of normal operating band).

If this sample indicates a higher than expected oxygen concentration,
then additional samples are taken at other potential air ingress
points, e.g.:

- Charging pump suction
- VCT
- RCS makeup to the VCT
- Reactor water storage tank
- Purification system ion exchanger



C. POST-EPISODE CHEMISTRY HISTORY

An examination of post-episode trends of significant chemistry parameters generates the following observations:

- (1) pH (Figure C.1) was controlled within the normal pre-episode guidelines established by CENPD-28.
- (2) Conductivity (Figure C.2) was consistent with the concentration of chemical additives. New baseline level was increased above pre-episode concentration due to the presence of hydrazine in the RC makeup water.
- (3) Lithium (Figure C.3) was reduced to pre-episode levels of less than 1.0 ppm toward the end of March 1980.
- (4) Suspended solids (Figure C.4) was controlled to within pre-episode levels less than 25 ppb and well within the guidelines of both CE and site specific guidelines of less than 500 ppb.
- (5) Hydrogen (Figure C.5) was controlled within the upper portion of the allowable band to ensure an adequate hydrogen inventory in the RCS.
- (6) Oxygen/Hydrazine (Figure C.6) Hydrazine was maintained well in excess of measured oxygen levels in accordance with CE guidelines. RCS oxygen values continued to remain within the pre-episode recommended specifications.
- (7) Iodine 131/133 Activities (Figures C.7,8) Reflects no adverse effect of the power distribution episode on fuel performance.
- (8) Ammonia (Figure C.9) is consistent with the concentration of hydrazine injected into the RCS. Observed levels were within the CE guidelines.

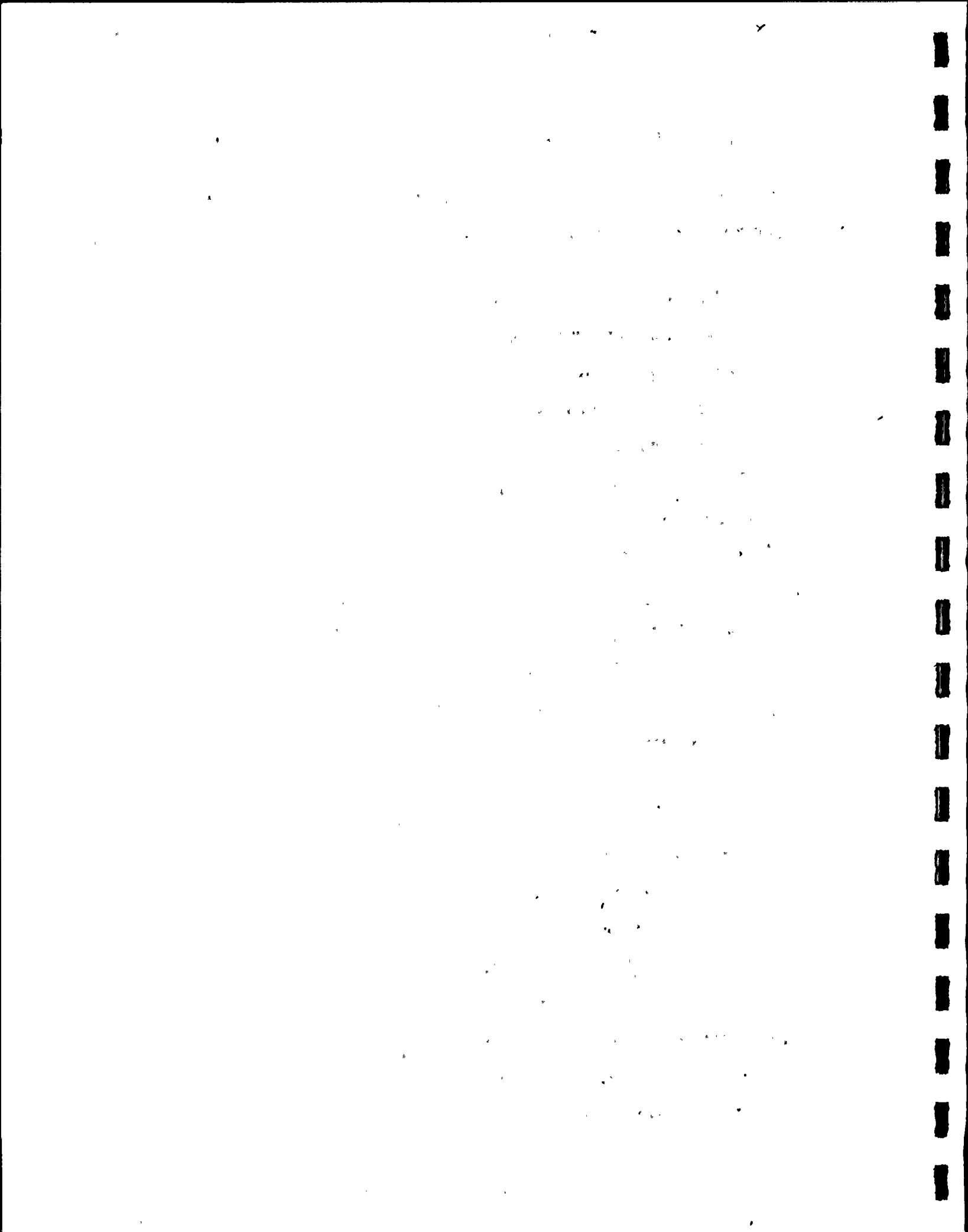
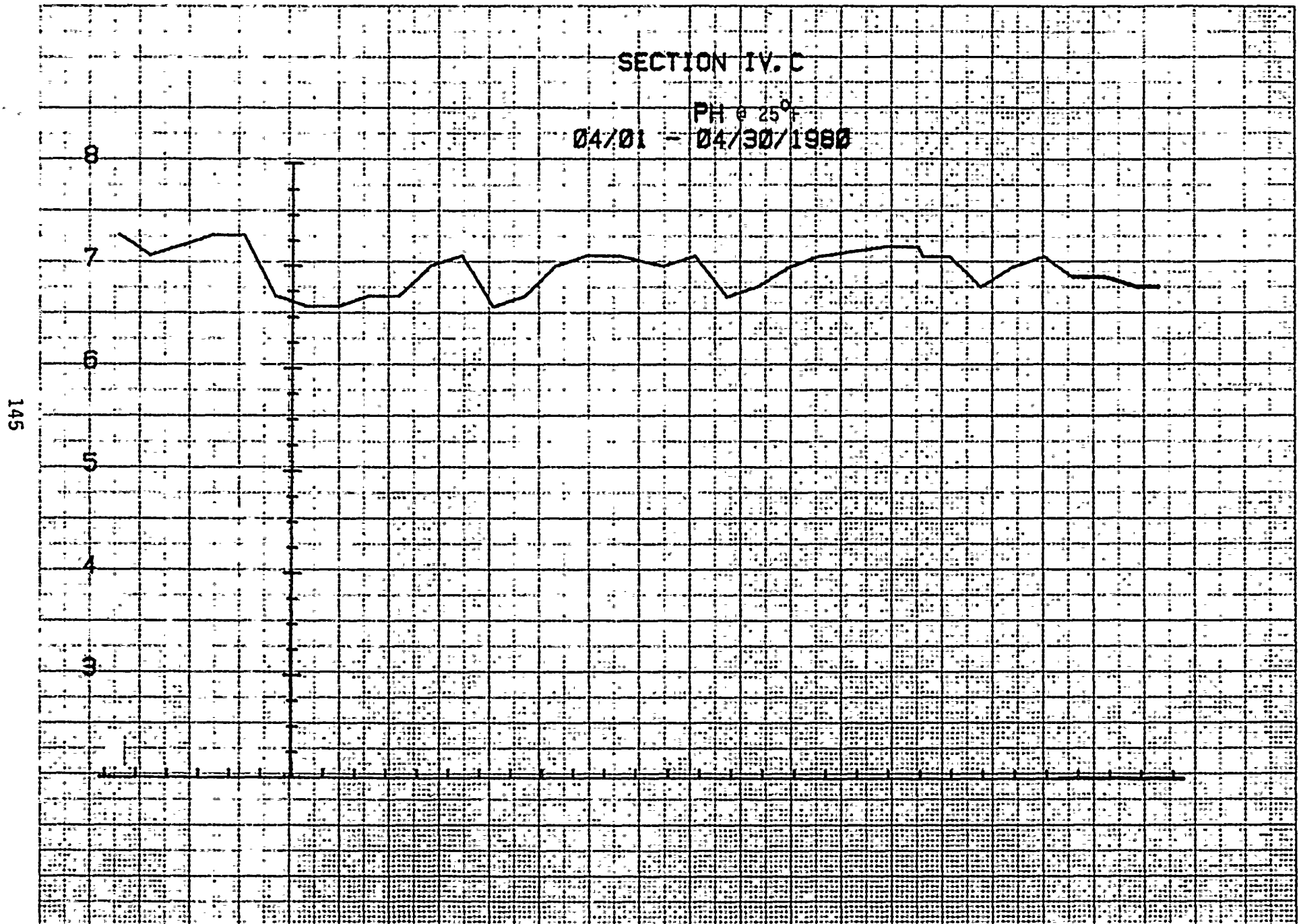


FIGURE C.1



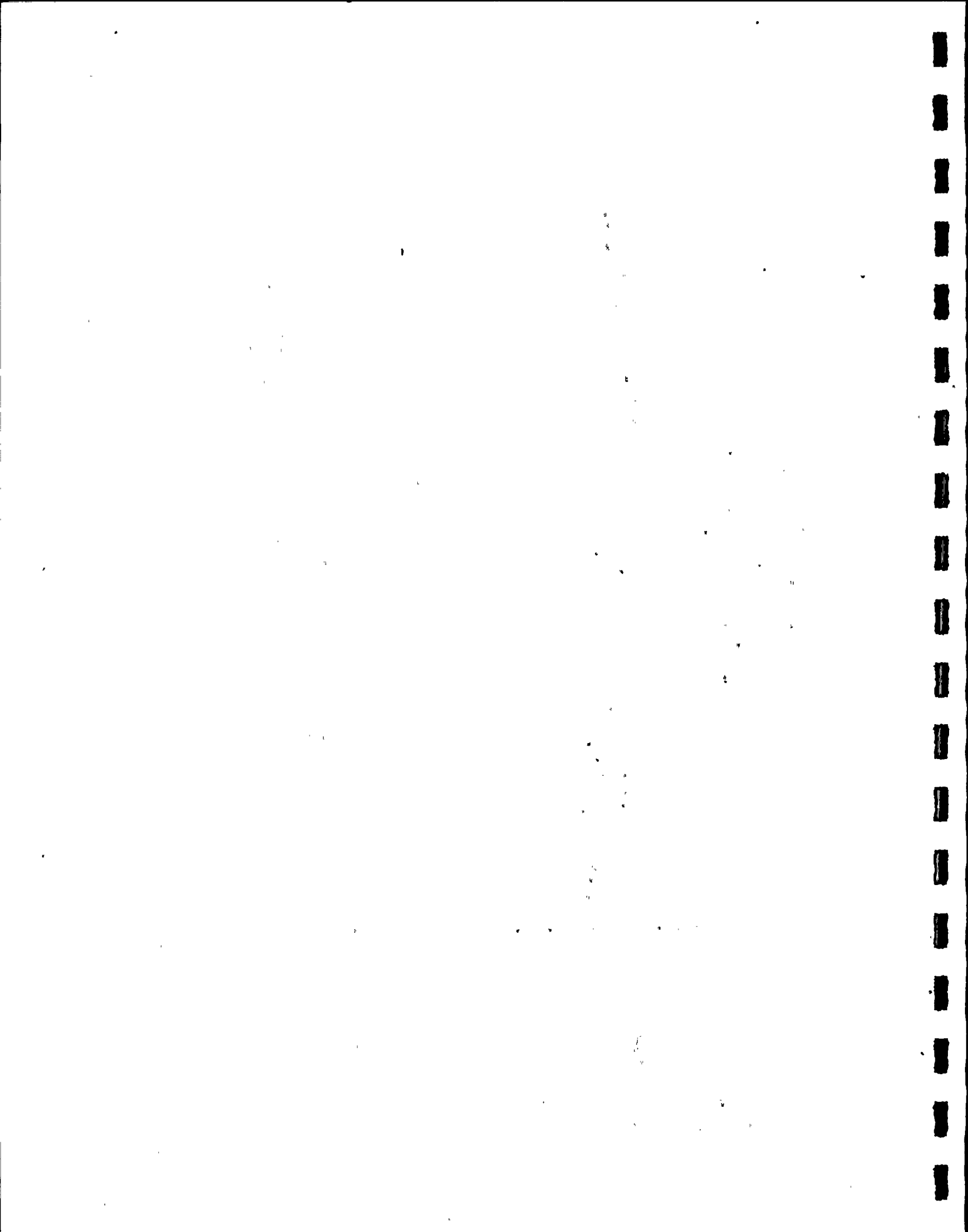


FIGURE C.2

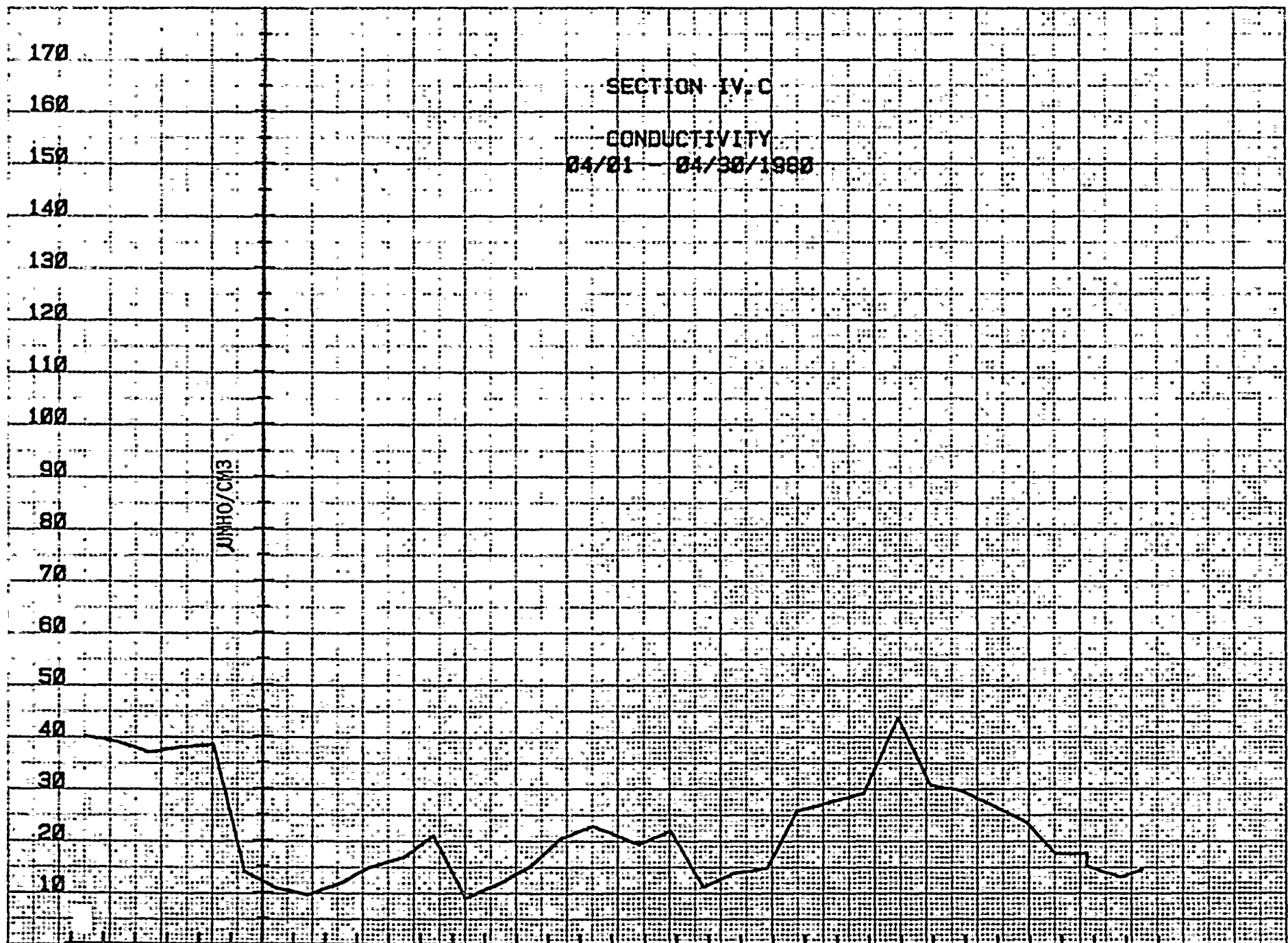


FIGURE C.3

SECTION IV.C
LITHIUM
04/01 - 04/30/1980

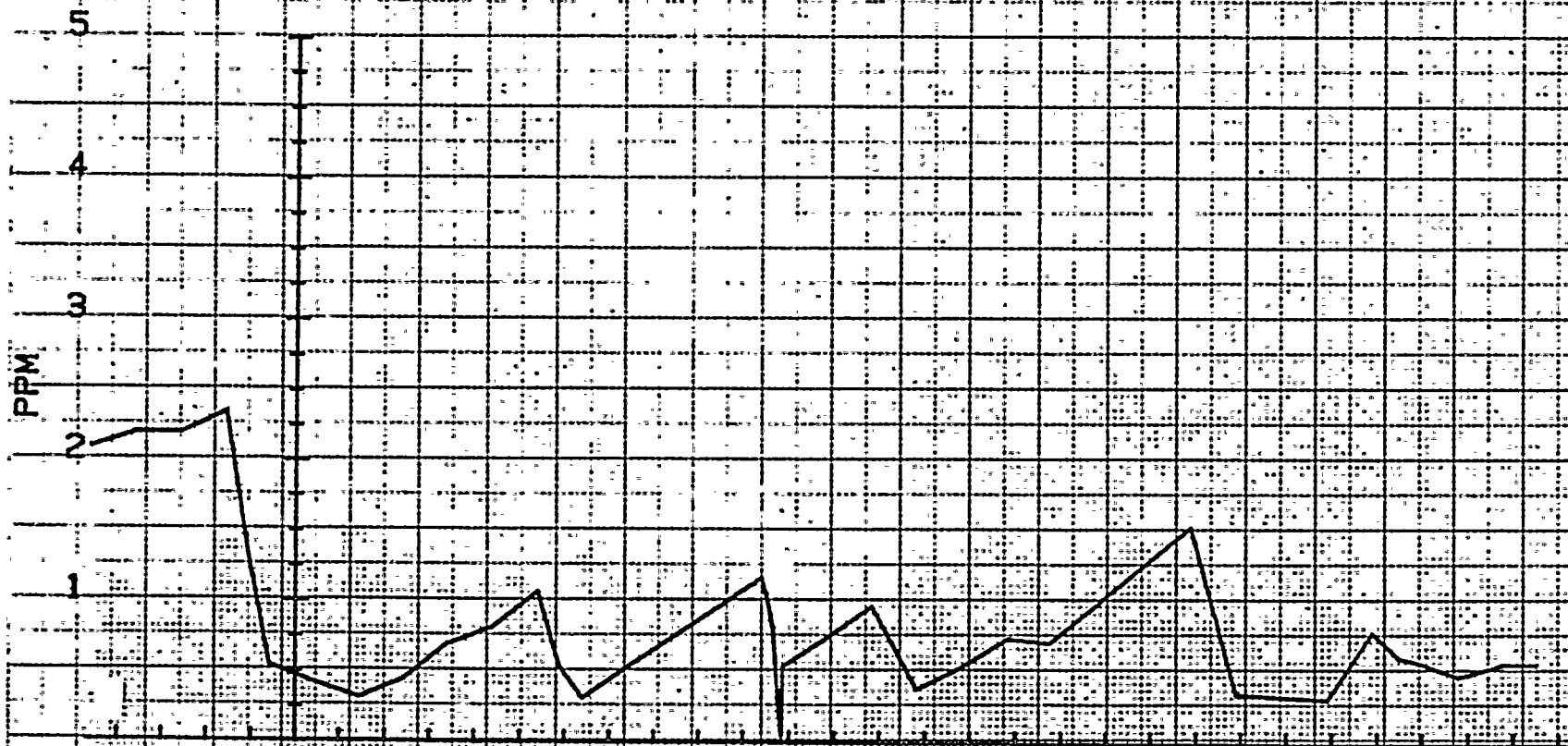


FIGURE C.4

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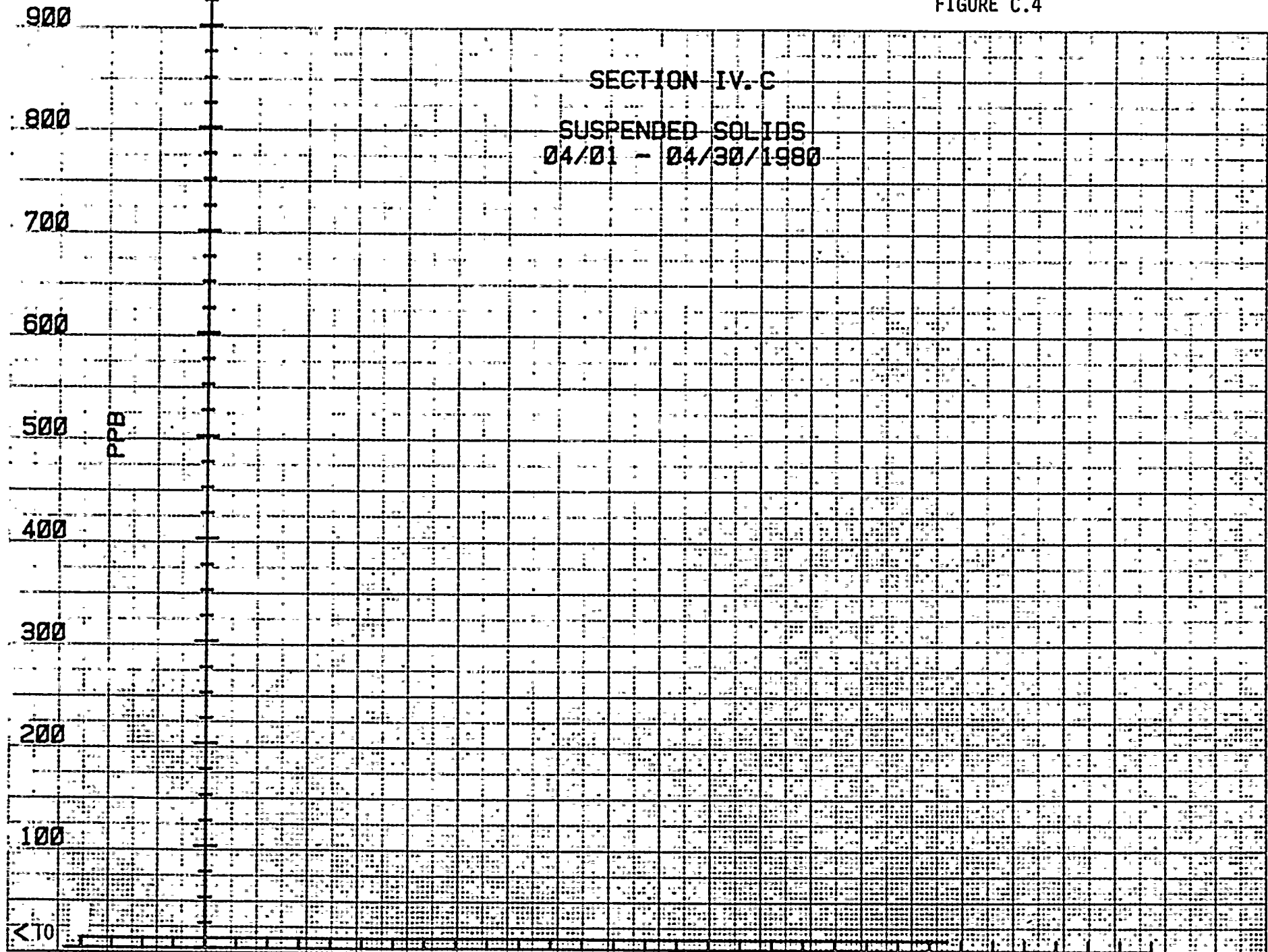
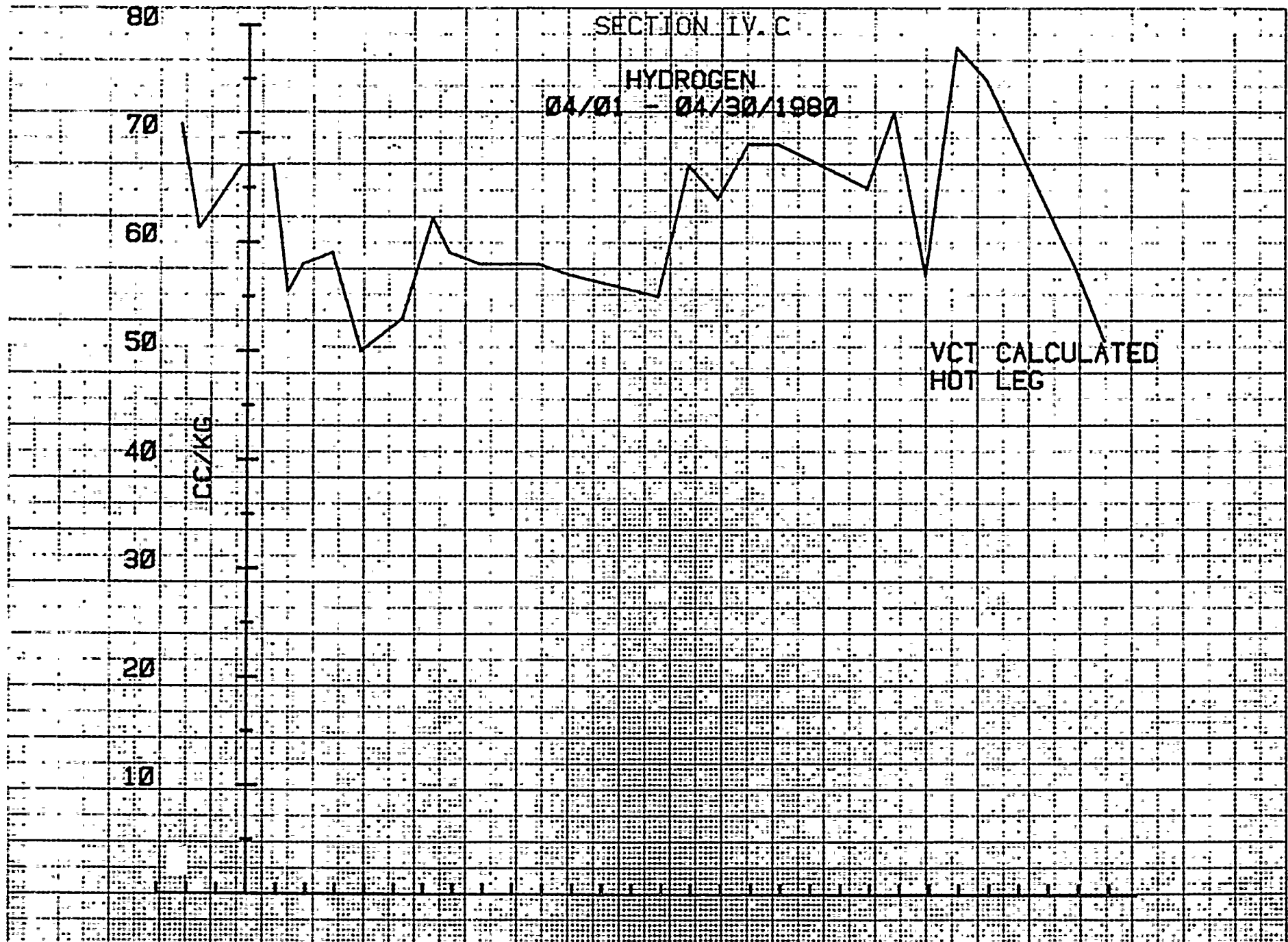


FIGURE C.5



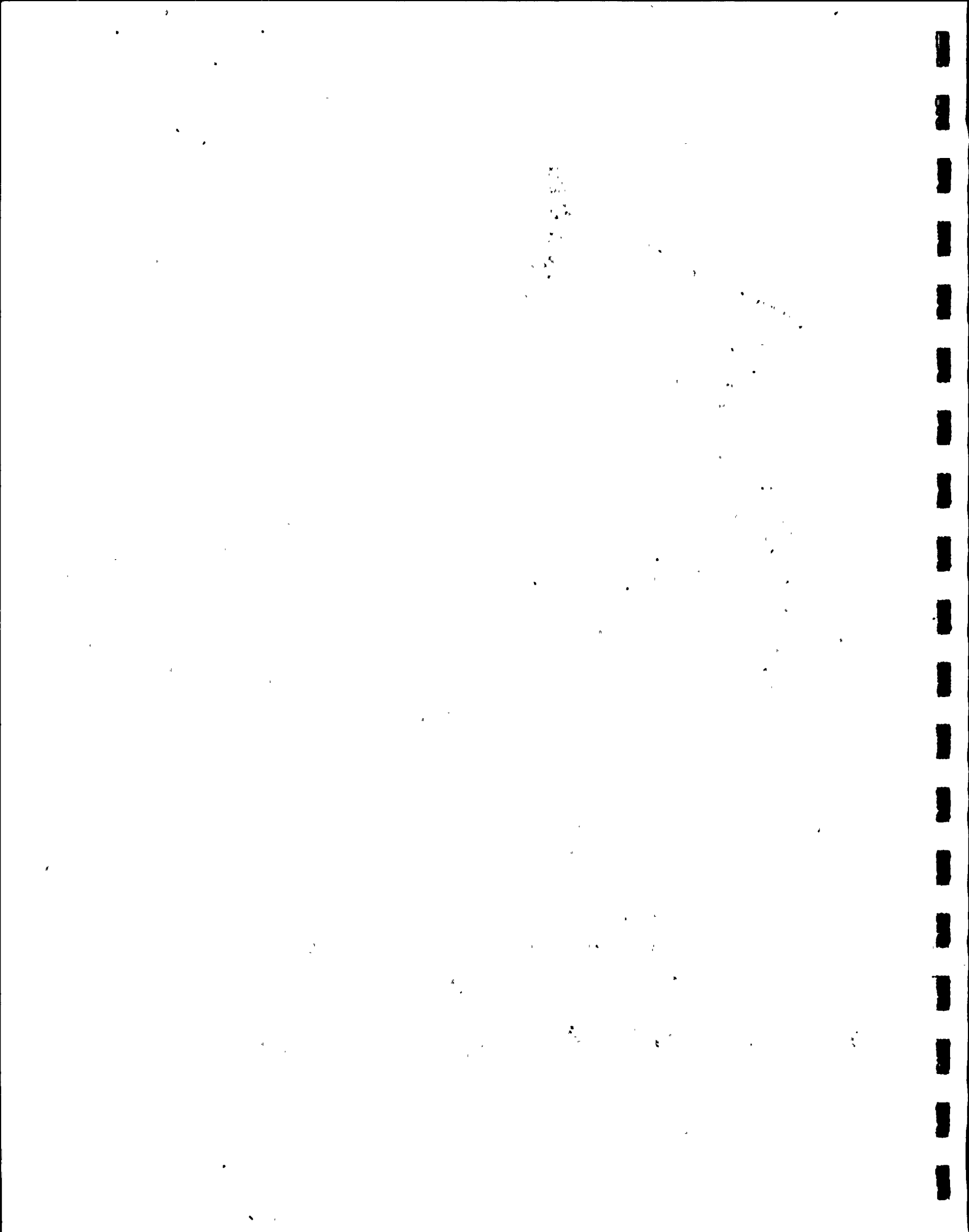


FIGURE C.6

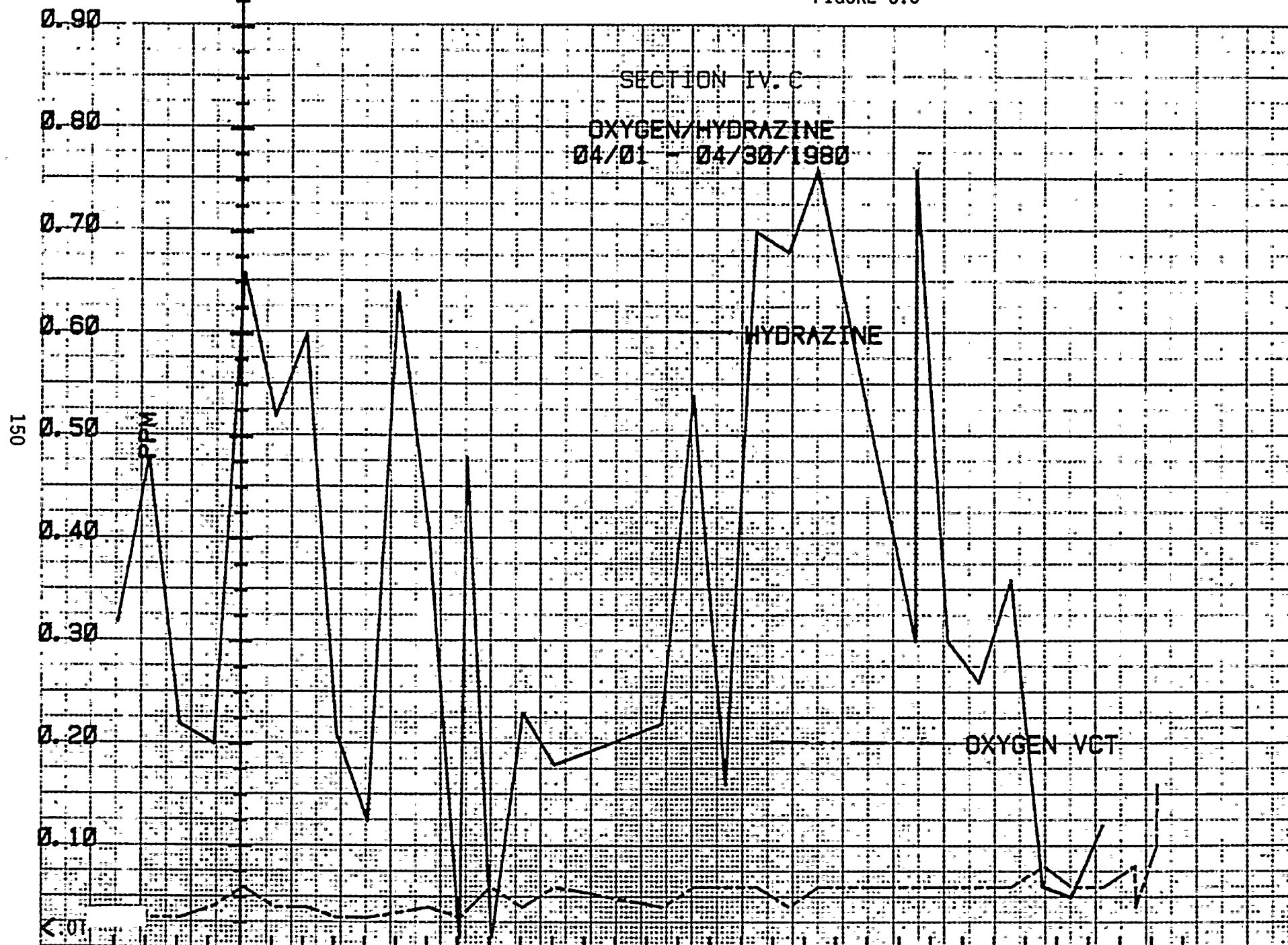
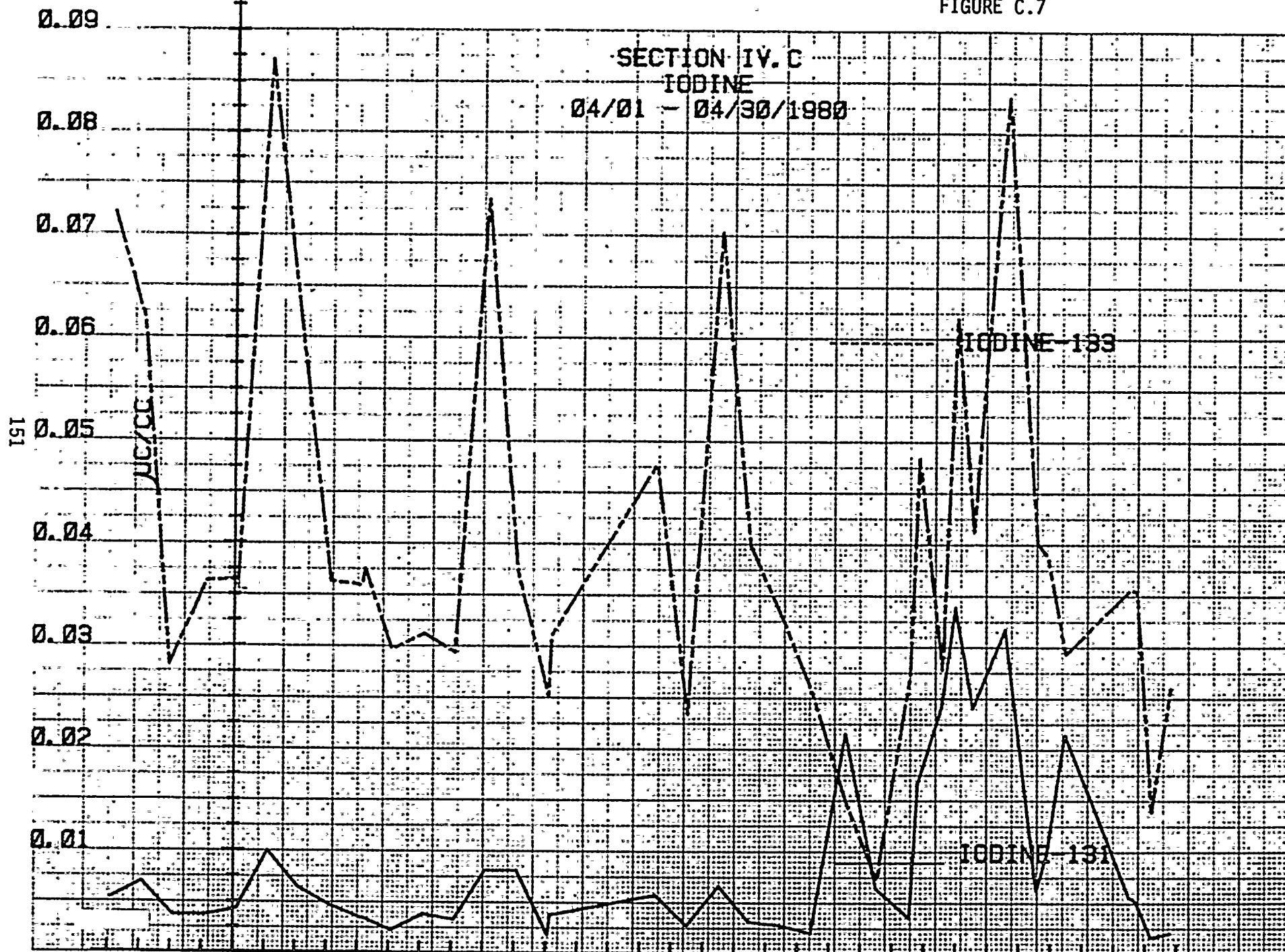


FIGURE C.7



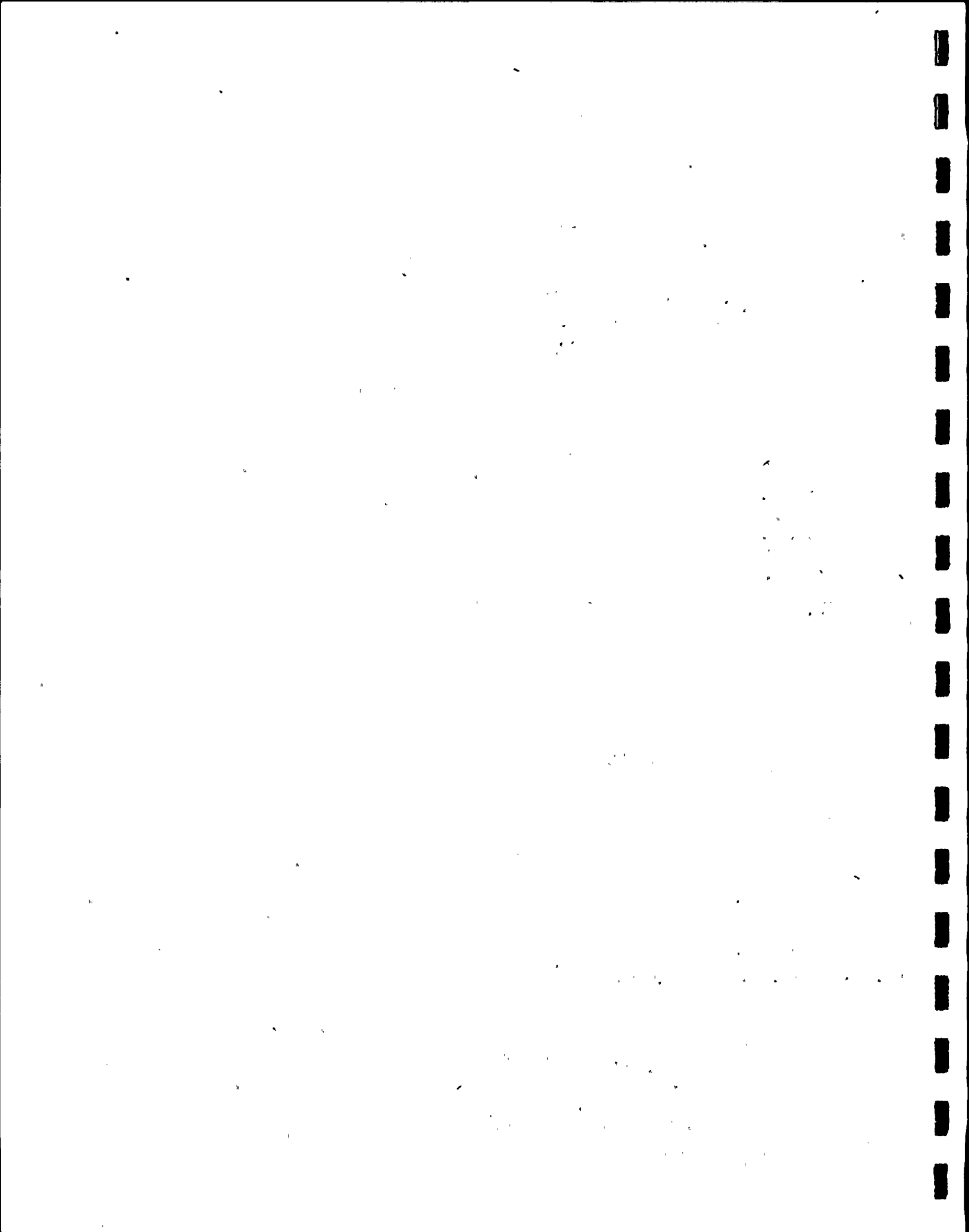
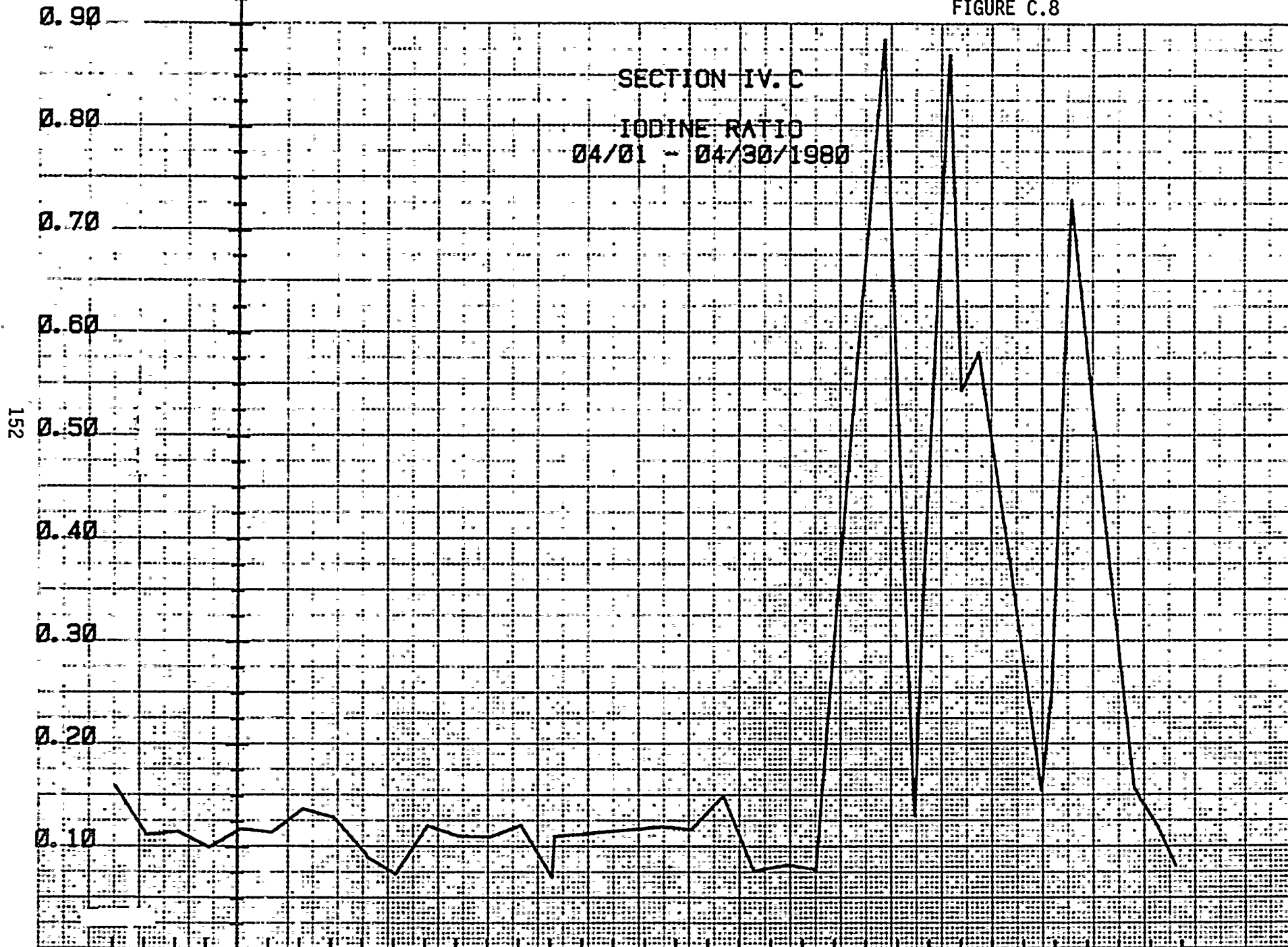


FIGURE C.8



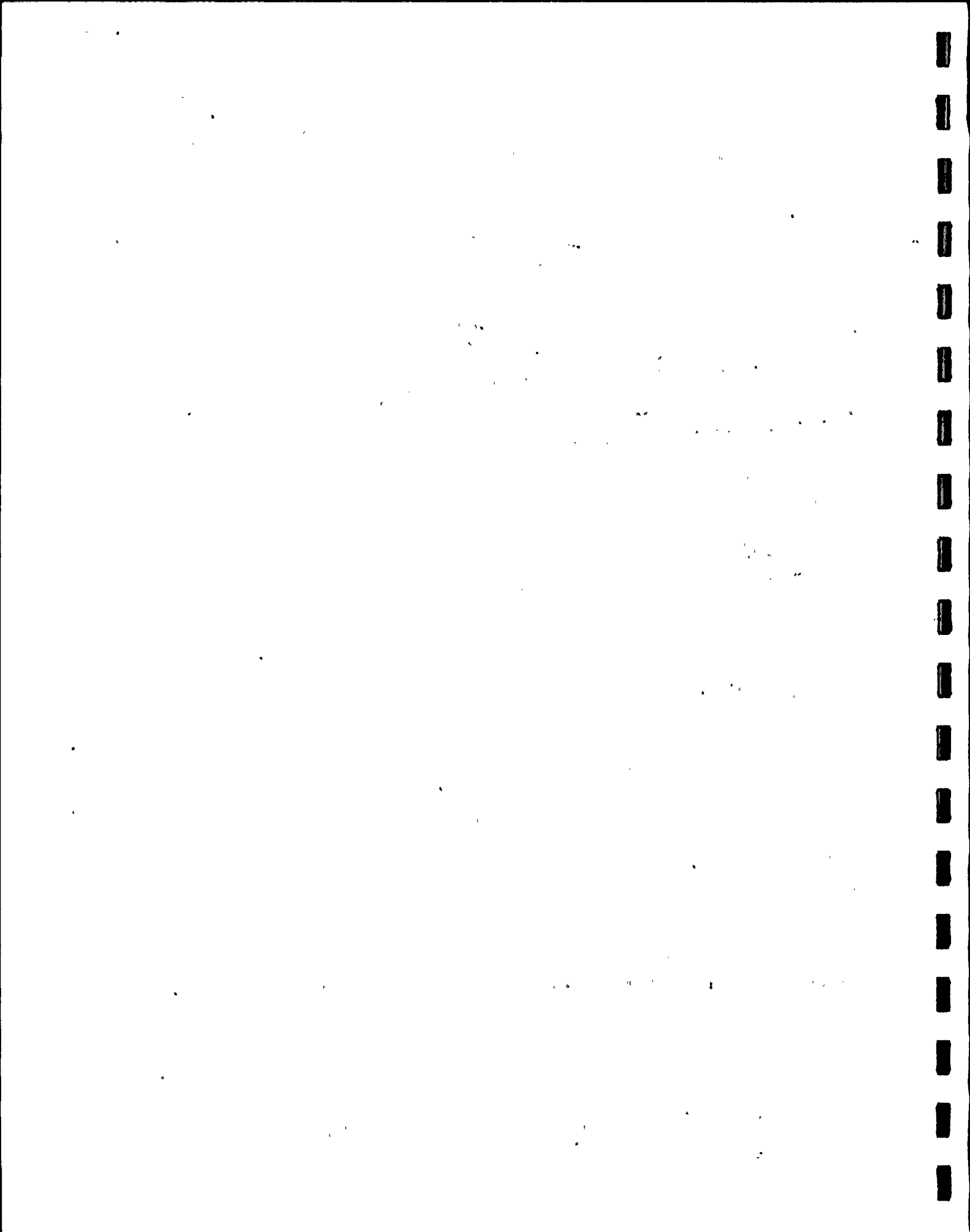
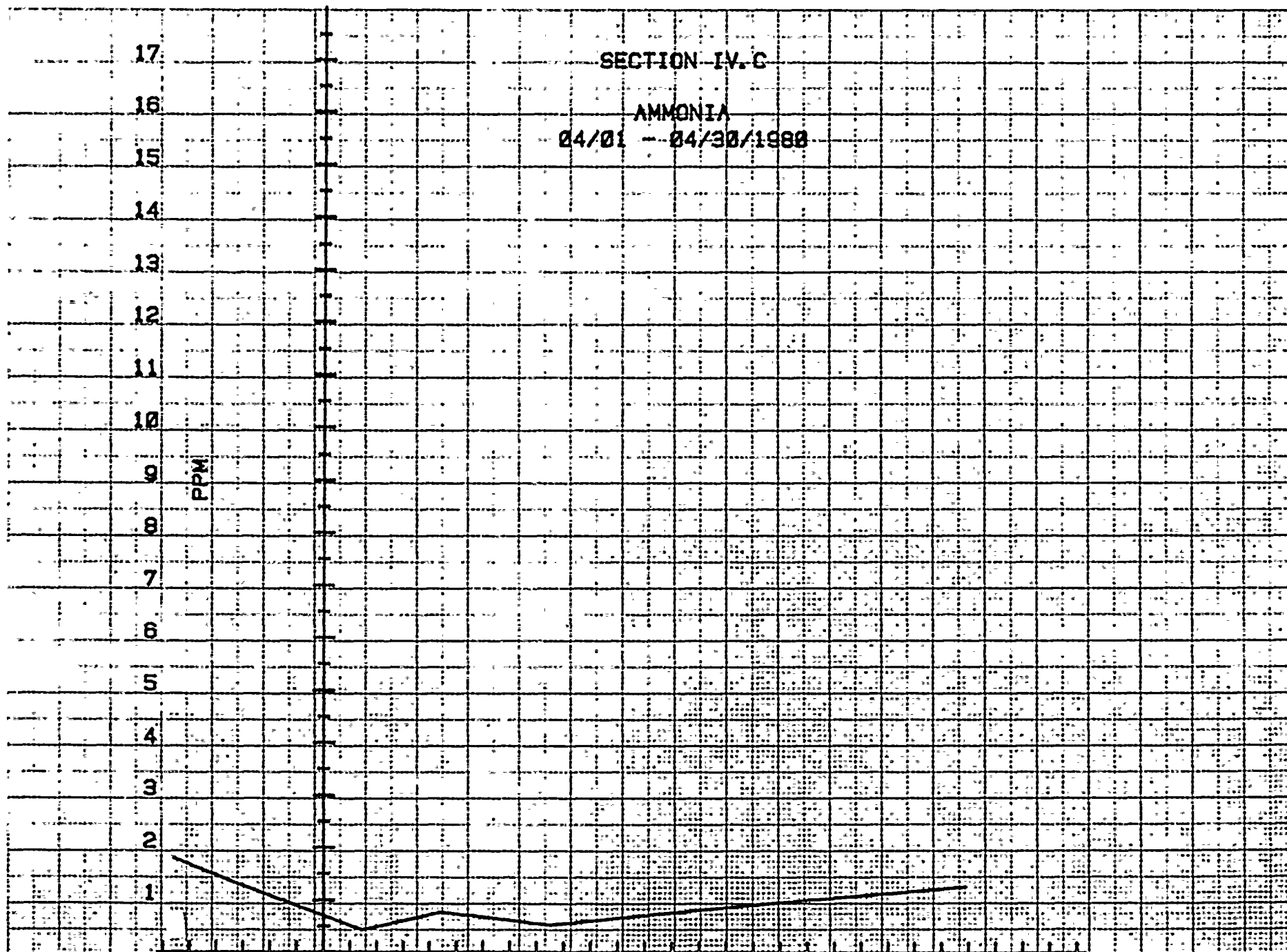
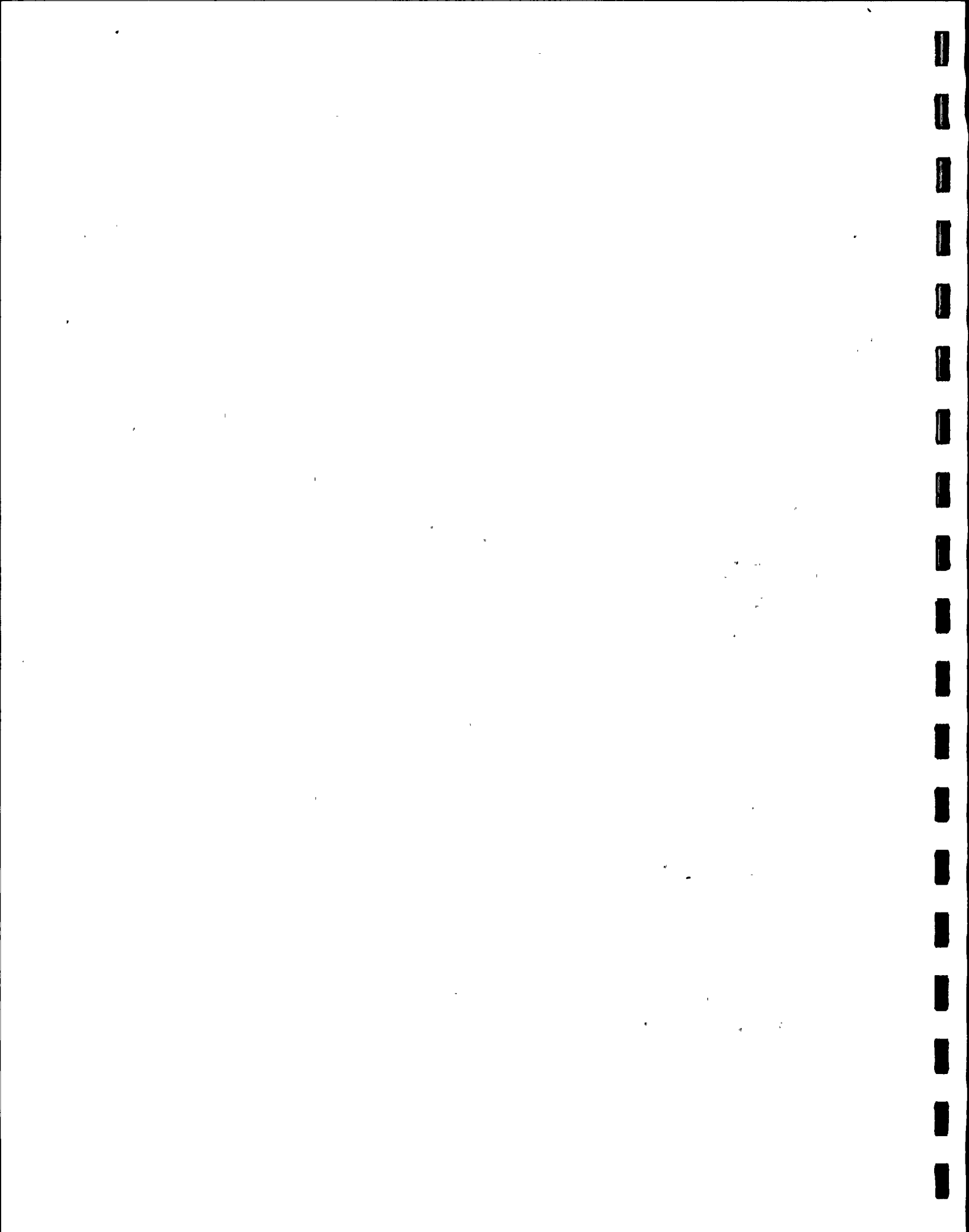


FIGURE C.9





D. PERMANENT MODIFICATIONS TO THE ROUTINE WATER CHEMISTRY SURVEILLANCE PROGRAM

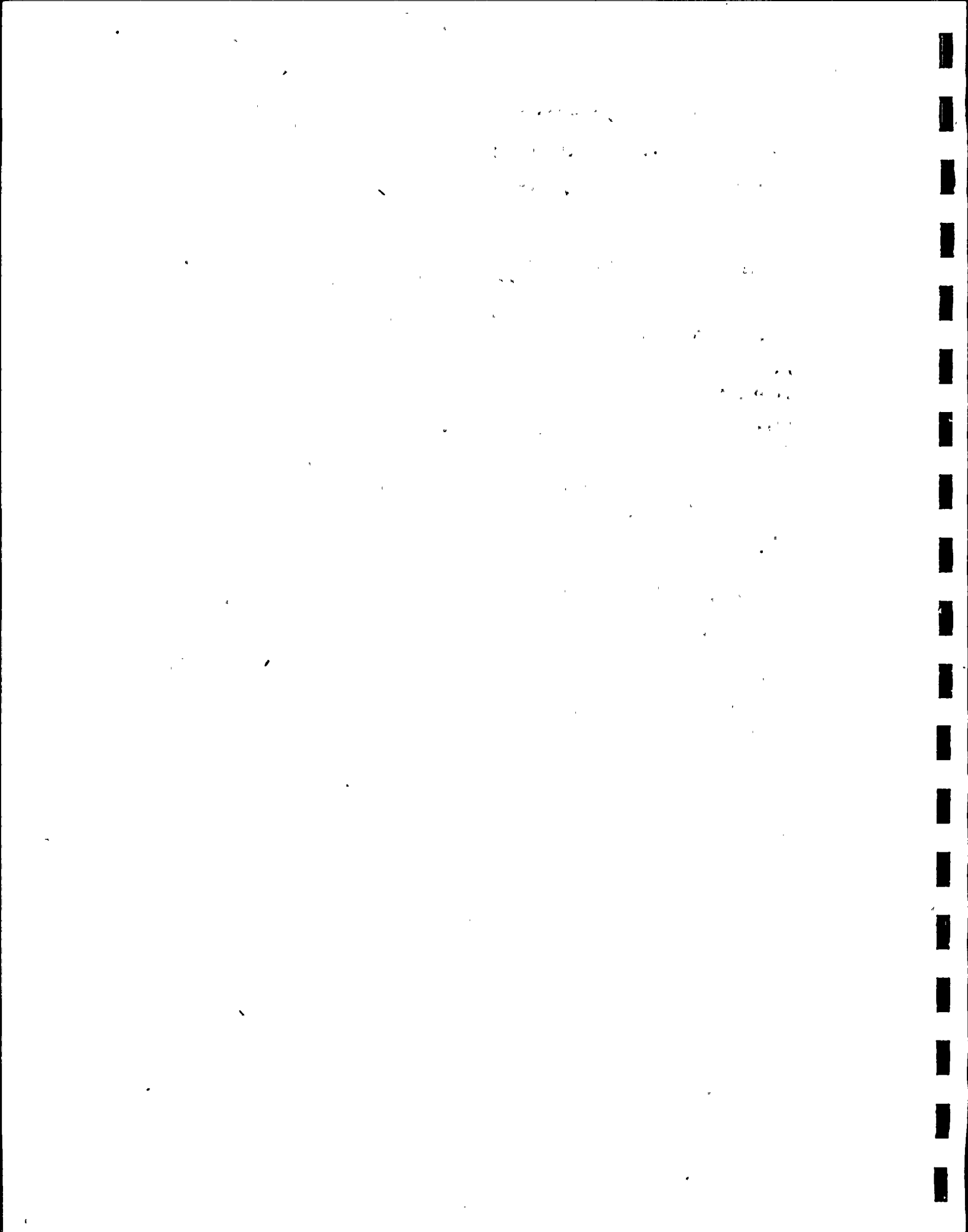
The significant changes incorporated into the routine water surveillance chemistry program are summarized below:

- (1) Modifications to the frequency and surveillance location for RCS hydrogen.
- (2) Increased surveillance frequency for analytical methodology associated with monitoring for fuel performance (iodine activities).
- (3) Incorporation of a correction factor for the RCS hotleg hydrogen determination to compensate for the inefficiency of the gas purging evolution at the degassing station.
- (4) Maintenance of VCT physical parameters at levels that will ensure adequate hydrogen concentrations are maintained in the VCT and therefore, in the RCS.
- (5) Increased Control/Analysis for CVCS hydrazine/oxygen to minimize oxygen ingress into the RCS.
- (6) Detailed procedures for the injection of hydrazine into the CVCS to minimize control problems.

In addition, the feasibility of installing a permanent deaerator in the effluent of the demineralized water storage tank is being evaluated. It is projected that the installation of the deaerator will minimize oxygen ingress into the RCS and eliminate operational problems associated with injection of the oxygen scavenger, hydrazine, and the subsequent RCS chemistry perturbations (ammonia, resin equilibrium).

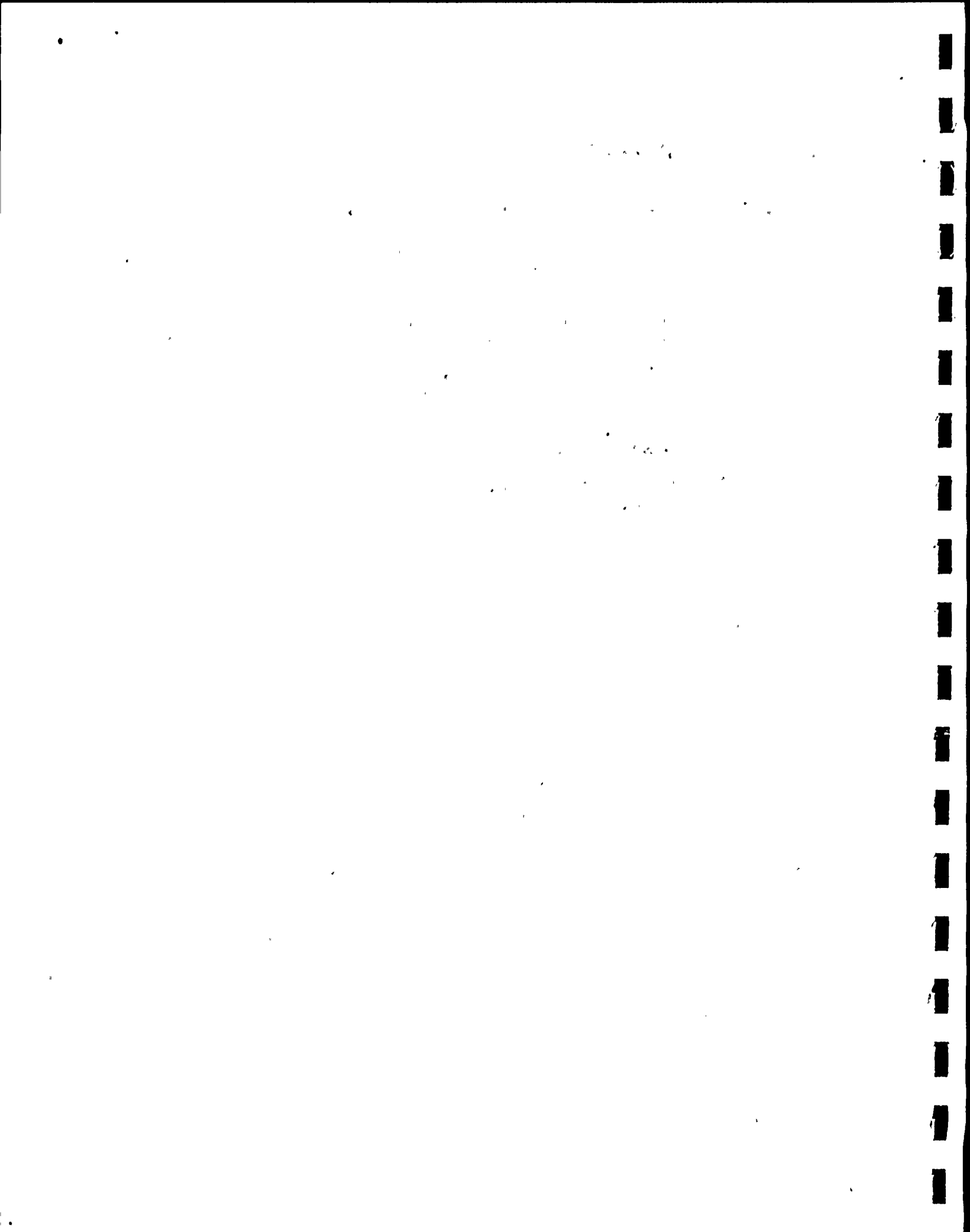
The table below lists the nominal values obtained for significant chemistry following the power distribution episode compared to pre-episode values. It also lists the post-episode specifications.

<u>Parameters</u>	Pre-Episode Nominal Value	Post-Episode Nominal Value	Post-Episode Specification
1) pH @ 25°C (Standard Units)	5.0 to 7.0	6.5 to 7.5	4.5 to 10.2
2) Conductivity (μmhos/cm)	0.0 to 20.0	10.0 to 40.0	Consistent w/ additives
3) Lithium (ppm)	0.0 to 1.0	0.0 to 1.0	1.0 ppm maximum
4) Suspended Solids (ppb)	0.0 to 250	<25 ppb	500 ppb maximum based on VCT Hydrogen
5) Hydrogen (cc/kg)	10-30	50-70	Consistent w/over- pressure & concentration in VCT
6) Oxygen/Hydrazine	N/A	5:1 ratio	5:1 ratio
7) Oxygen (ppb)	<10	<10	<100
8) Ammonia (ppb)	10	1000	Not Specified
9) Fuel Performance Parameters	N/A	N/A	N/A



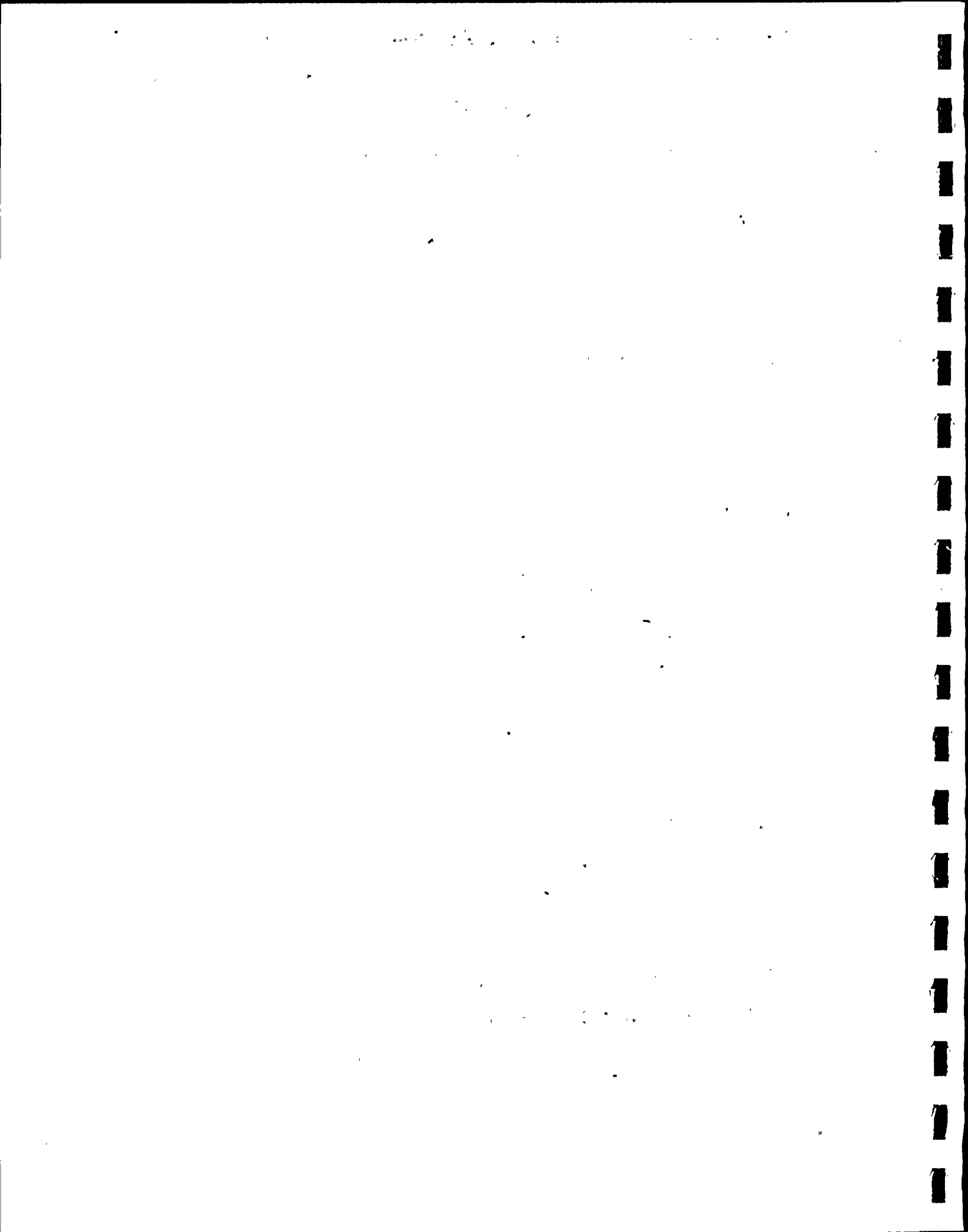
E. SECTION IV ATTACHMENTS

- (1a-d) Calvert Cliffs Instruction #406, Index of Rad-Chem Procedures.
- (2a-b) RCP-1-202. Specifications and Surveillance. Reactor Coolant System. Table 1.
- (3a-d) Reactor Coolant System - Operating Chemistry Specification Sheet #3-3. CENPD-28.
- (4) RCP-1-215. Specifications and Surveillance Chemical and Volume Control System. Table 1.
- (5) RCP-1-201. Specifications and Surveillance Makeup Demineralized Water System. Table 1.
- (6a-b) Makeup Water System - Operating Chemistry Specification Sheet #2-1. CENPD-28.



RCP 1 - 100	Series - General Information	
1 - 101*	Methods for Revising and Changing Rad-Chem Procedures	8
1 - 102*	Records	4
1 - 103	QC Procedure	3
1 - 104	Standard Safety Precautions	1
RCP 1 - 200	Specification & Surveillance Scope of Section 200	4
1 - 201*	Make-up Demineralized Water	4
1 - 202*	Reactor Coolant System	8
1 - 203*	Component Cooling/Service Water System	3
1 - 204*	Refueling & Spent Fuel Pool System	6
1 - 205*	Safety Injection System	4
1 - 206*	Liquid Waste Releases	12
1 - 207*	Boric Acid Storage Tanks	9
1 - 208*	Boric Acid Storage Tanks	7
1 - 209	Domestic Water System	0
1 - 210*	Steam Generators	8
1 - 211*	Condensate, Feedwater and Main Steam System	8
1 - 212	Sewage Treatment Plant	4
1 - 213*	Neutralizing Tank	1
1 - 214	Auxiliary Boilers	4
1 - 215*	CVCS Systems	6
1 - 216*	Stator Cooling System	0
1 - 217*	Diesel Gen. Jacket Cooling	2
1 - 218	Unmonitored Discharge Surveillance Program	1

*Required POSRC Review



ATTACHMENT (ID)
INDEX OF WATER CHEMISTRY AND RADIOCHEMISTRY PROCEDURES MANUAL - RCP 1

RCP 1 -	Series -	(future use)	<u>CURRENT REV. #</u>
RCP 1 - 300	Series -	(future use)	
RCP 1 - 400	Series -	(future use)	
RCP 1 - 500	Series -	Sampling Requirements	
1 - 501*	Sampling Techniques		0
1 - 502*	Sampling of Cases for Activity		3
1 - 503*	Post-Accident Sampling of Reactor Coolant & Containment Conditions		0
RCP 1 - 600	Series -	(future use)	
RCP 1 - 700	Series -	(future use)	
RCP 1 - 800	Series -	(future use)	
RCP 1 - 900	Series -	Water Chemistry Procedure	
1 - 901	Determination of Conductivity		0
1 - 902	Determination of pH		2
1 - 903	Determination of Boron		3
1 - 904	Determination of Gases		1
1 - 905	Determination of Dissolved Oxygen		1
1 - 906	Determination of Chloride		3
1 - 907	Determination of Fluoride		1
1 - 908	Determination of Lithium and Sodium		1
1 - 909	Determination of Ammonia		1
1 - 910	Determination of Hydrazine		2
1 - 911	Determination of Suspended, Dissolved and Total Solids		3
1 - 912	Determination of Total Hardness		0
1 - 913	Determination of Alkalinity		1

*Required POSRC Review

ATTACHMENT (1c)

INDEX OF WATER CHEMISTRY AND RADIOCHEMISTRY PROCEDURES MANUAL - RCP 1

CURRENT REV. #

RCP 1 - 914	Determination of Phosphate	0
1 - 915	Determination of Chromate	0
1 - 916	Determination of Soluble Silica	2
1 - 917	Determination of Nickel	1
1 - 918	Determination of Total Iron	1
1 - 919	Determination of Copper	0
1 - 920	Determination of Sulfite	0
1 - 921	Determination of Free Hydroxide	0
1 - 922	Determination of Residual Chlorine	3
1 - 923	Determination of Morpholine	1
1 - 924	Determination of Sewage Treatment Plant Chemistry	0
1 - 925	Determination of Turbidity	0
1 - 926	Determination of Chromium	1
1 - 927	Determination of Chloroform Populations in Domestic and Waste Water	1
1 - 928	Determination of Oil and Grease	1
RCP 1 - 1000	Series - Radiochemistry Procedures	1
1 - 1001*	Determination of Gross Beta-Gamma (Alpha) Degassed Activity	3
1 - 1002	Determination of Gaseous Activity	0
1 - 1003	Determination of Iodine Activity	1
1 - 1004	Radiochemical Analysis for Radioactive Cesium	0
1 - 1005	Determination of Barium and Lanthanum	0
1 - 1006	Determination of Strontium Activity	3
1 - 1007*	Determination of Tritium Activity	4
1 - 1008	Determination of Corrosion Product Activity	0

*Required POSRC Review

Ch. 9

1 - 1009	Determination of \bar{E}	3
RCP 1 - 1100	Series - Purchase Specification	1
1 - 1101	Plant Chemicals	0
1 - 1102	Resins	1
RCP 1 - 1200	Series - Special Procedures	
1 - 1201	Auxiliary Boilers	0
1 - 1202	Determination of Water and Sediment in Fuel Oils	0
1 - 1203*	Determination of the Ability of TSP to Dissolve	2
1 - 1204	Observation Well Depth Recorder & Well Water Usage Records	1
1 - 1205	Special Procedure for Nuclear Grade Resin Surveillance	0
1 - 1206*	Special Procedure for Reactor Coolant System Hydrogen Peroxide Treatment	0

SPECIFICATIONS AND SURVEILLANCE

REACTOR COOLANT SYSTEM

TABLE I

HOT LEG (OR LETDOWN SX 6458)

ANALYSIS/PROCEDURE	SPECIFICATION	FREQUENCY A (1)	FREQUENCY B (1)
1. pH @ 25 C/902	4.5 - 10.2	5/W	3/W
2. Specific conductivity/901	Consistent with conc. of additives	5/W	3/W
3. Boron/903 (Tech Spec 3.1.1 & 3.9.1)	Variable	5/W (2)	1/24hrs. (2)
4. Lithium/908	1ppm (max) (3)	5/W	3/W
5. Chloride/906 (Tech Spec 3.4.7)	0.15ppm (max)	1/72hr.	1/72hrs.
6. Fluoride/907 (Tech Spec 3.4.7)	0.15ppm (max)	1/72hrs.	1/72hrs.
7. Suspended Solids/911	0.5ppm (max)	1/W	1/W
8. Hydrazine/910	1.5x measured O ₂ conc.	(4)	None
9. Ammonia/909	(5)	1/W	None
10. Oxygen/905 (Tech Spec 3.4.7)	0.10ppm (Max) (6)	1/72hrs.	None
* 11. Hydrogen/904	10-50cc/kg (7)	1/W	None
12. Nitrogen/904	Not specified	As Required	AS REQUIRED
13. Total Activity (Tech Spec 3.4.8)	100/E uCi/g (max)(8)	1/72hrs.	1/W
14. I ¹³¹ Dose Equivalent (Tech Spec 3.4.8)	1 uCi/g (8)	1/14days	None
15. Gross 8 ⁹ Degassed Activity	Not specified	1/W	1/W
16. Gross Alpha Activity/1001	Not specified	1/W	1/W
17. I ¹³¹ /I ¹³³ Ratio/1003	Not specified	1/W	(deleted)
18. Tritium/1007	Not specified	1/W	1/W
19. Crud Activity/1008	Not specified	1/M	1/M
20. E Determination/1009 (Tech Spec Table 4.4-4)	Not specified	1/6mths.	None
21. Iodine isotopic analysis (Tech Spec 3.4.8)	Not specified	(9)	(9)

SPECIFICATIONS AND SURVEILLANCE

REACTOR COOLANT SYSTEM

TABLE I

NOTES

- (1) Frequency A = Modes 1, 2, 3, 4
Frequency B = Modes 5, 6
- (2) Required 1/24 hrs. to verify shutdown margin per Tech. Spec. 3.1.1. in Mode 5.
In Mode 6, 1/72 hrs. as per Tech. Spec. 3.9.1.
- (3) Normal range 0.2 to 1.0ppm. Lithium should be maintained 0.2-0.5 when B \leq 50ppm.
- (4) Prior to exceeding 150° F. The presence of hydrazine will be verified following any chemical addition of hydrazine to the coolant.
- (5) Normal concentration about 1.0ppm.
- (6) Must be within specification prior to heatup 7250 F.
- (7) Hydrogen must be maintained within these limits for all plant operation above LMWT. Less than 5cc H₂/kg H₂O (STP) is required for opening the reactor coolant system to atmosphere.
- (8) If the total activity $> 100/\bar{E}$ uCi/g or > 1.0 uCi/g dose equivalent I-131 perform analysis #21 of this procedure 1/4 hrs. until the activity is returned to within specification.
- (9) This analysis shall be performed according to the following schedule:
 - a) Once per 4 hours, whenever the dose equivalent I-131 exceeds 1.0 uCi/gram (until the RCS specific activity is restored, within its limits), and
 - b) One sample between 2 and 6 hours following a thermal power change exceeding 15% of the rated thermal power within a one hour period.



SUMMARY OF REACTOR COOLANT CHEMISTRY SPECIFICATIONS

<u>Analysis</u>	<u>Precore</u>	<u>Core Loading</u>	<u>Operating</u>
pH @ 77°F	9.0 - 10.4	4.5 - 10.2	4.5 - 10.2
Conductivity	Note 1	Note 1	Note 1
Hydrazine	30 - 50 ppm	30 - 50 ppm	1.5 X Oxygen ppm (max. 20 ppm)
Ammonia	<50 ppm	<50 ppm	<0.5 ppm
Dissolved Gas	----	----	<10 $\frac{\text{cm}^3}{\text{kg H}_2\text{O}}$ (STP) prior to a depressur- ization shutdown
Oxygen	<0.1 ppm	<0.1 ppm	<0.1 ppm
Suspended Solids	<0.5 ppm 2.0 ppm max.	<0.5 ppm 2.0 ppm max.	<0.5 ppm 2.0 ppm max.
Chloride	<0.15 ppm	<0.15 ppm	<0.15 ppm
Fluoride	<0.1 ppm	<0.1 ppm	<0.1 ppm
Boron	----	Refueling Concentration <4400 ppm	
Lithium	1 to 2 ppm (Note 2)	0.2 - 1.0 ppm (Note 3)	0.2 - 1.0 ppm
Hydrogen	----	----	10 - 50 $\frac{\text{cm}^3}{\text{kg H}_2\text{O}}$ (STP) (Note 4)
Iodine-131	----	----	Note 5
Tritium	----	----	Note 5
Reactor Coolant Liquid Activity	----	----	Note 5
E	----	----	Note 5

NOTE 1: Consistent with concentration of additives.

NOTE 2: Refer to Section 3.3.2.1 for the length of time this specification will be in force.

NOTE 3: If the purification ion exchanger is being saturated in situ with ^7Li maintain 1-2 ppm Li until saturation is reached (indicated by Li breakthrough), then revert to 0.2 - 1.0 ppm ^7Li . Saturation should be accomplished prior to criticality.NOTE 4: <5 cm^3 (STP)/kg(H_2O) before securing the reactor coolant pumps.

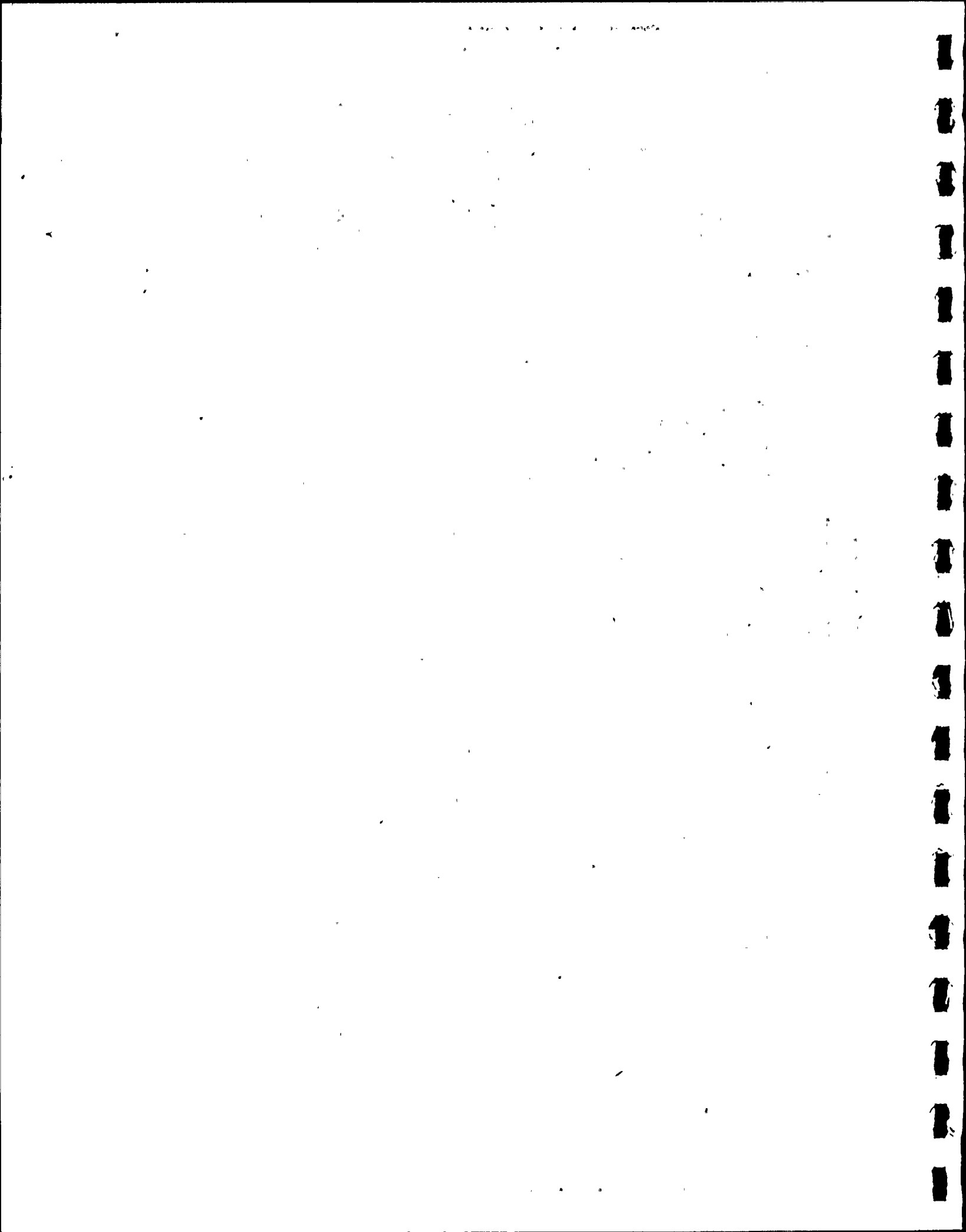
NOTE 5: See FSAR, Technical Specifications.

SPECIFICATION SHEET NO. 3-3

SYSTEM REACTOR COOLANT - OPERATING

Analysis	Sample Location	Sampling ^(a) Frequency	Specifications	Corrective Action	Notes
pH (Measured at 25°C)	1. Hot Leg Loop or Purification Filter Inlet (PF Inlet) 2. Purification Ion Exchanger Outlet (IX Outlet)	5 1	4.5 to 10.2 ^(b)	1. Confirm value. 2. Perform O ₂ , H ₂ and lithium analysis to determine cause. 3. Valve in standby column, if high pH due to high lithium. 4. Add Li-7 if too low. 5. If pH change due to high O ₂ , follow corrective action under that heading.	(a) Frequency Code 1 = 1/week 2 = 2/week 5 = 5/week 2Y = 2/year S = During shutdowns and startups AR = As required (b) The pH limit of 10.2 must not be exceeded; see Section 3.3.2 for further discussion.
	Reactor Makeup Water Tank	1	6.0 - 8.0	1. Confirm value. 2. Drain and refill if req'd.	
Oxygen	1. Hot Leg Loop 2. Reactor Makeup Water Tank	5 1	Less than 0.1 ppm	1. Resample to confirm value. 2. If during heatup, add hydrazine ^(c) to 1.5 times O ₂ concentration. 3. Perform H ₂ analysis if at power, add H ₂ as required. 4. If pH and H ₂ also low out-of-spec, add N ₂ H ₄ .	(c) Hydrazine is added to recirculating reactor coolant during heatup if required to remove excess O ₂ . The system cannot exceed 150°F until the O ₂ operating limit or a hydrazine residual is established.
Hydrogen	Hot Leg Loop	2	10 to 50 cm ³ (STP) H ₂ /Kg H ₂ O	1. Add H ₂ as required. 2. Degas as required.	<5 cm ³ (STP)/kg H ₂ O before securing reactor coolant pumps
Total Dissolved Gas	Hot Leg Loop	AR	<10 cm ³ (STP)/ kg H ₂ O prior to shutdown	1. Degas as required.	

ATTACHMENT (3b)



SPECIFICATION SHEET NO. 3-3
SYSTEM REACTOR COOLANT - OPERATING (Continued)

Analysis	Sample Location	Sampling (a) Frequency	Specifications	Corrective Action	Notes
Ammonia ^(d)	Hot Leg Loop or PF Inlet	1	Less Than 0.5 ppm NH ₃	1. Initiate or increase purification flow. 2. Or reduce N ₂ content of Reactor Coolant, as applicable.	(d) Ammonia is due to hydrazine decomposi- tion or radiolytic combination of N ₂ and H ₂ .
Lithium	1. Hot Leg Loop or PF Inlet 2. IX Outlet ^(e)	Daily; after additions; and AR; (Note 1) 1	0.2 to 1.0 ppm	1. Initiate flow to de- lithiating bed if high. 2. Add Li-7 if Low.	(e) To determine when when bed saturation takes place during lithiation.
Boron	1. PF Inlet or Hot Leg Loop	5	(f)	Add boric acid or makeup as required.	(f) Boron concentration varies with burn- up. The predicted concentration is found in the Final Safety Analysis Report of each plant.
	2. Reactor Makeup Water Tank	1	Zero		
	3. Volume Control Tank Liquid	1	(f)		
	4. Refueling Water Tank	1	(f)		
	5. IX Outlet (when deborating)	1	(f)		
	6. Pressurizer	1	(f)		
Chloride	1. PF Inlet or Hot Leg Loop 2. IX Outlet	5 1	Less Than 0.15 ppm	1. Check IX Outlet 2. Initiate or increase purification flow.	NOTE 1: At least every 4 hours during boration or dilution operations. Prior to and after boration/dilution, operations, unless these are part of a casualty, then sampling should be ASAP.
Fluoride	3. Reactor Makeup Water Tank	1	Less Than 0.1 ppm	3. Check Reactor Water Makeup Tank and bleed and feed, as required.	
	4. Volume Control Tank Liquid	1		4. Isolate and shift columns. 5. Replace resin bed, as required.	

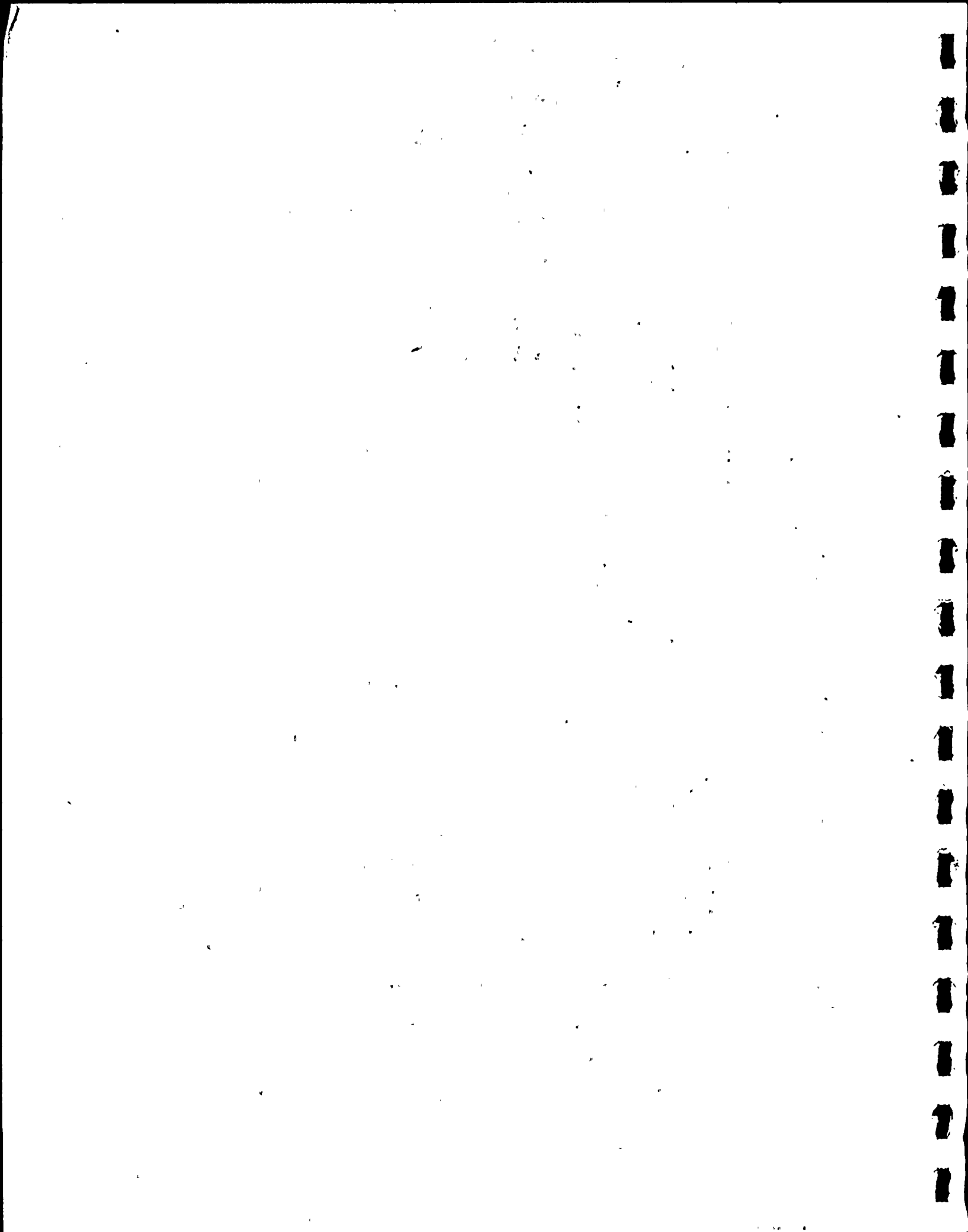
ATTACHMENT (3c)

SPECIFICATION SHEET NO. 3-3

SYSTEM REACTOR COOLANT - OPERATING (Continued)

ATTACHMENT (3d)

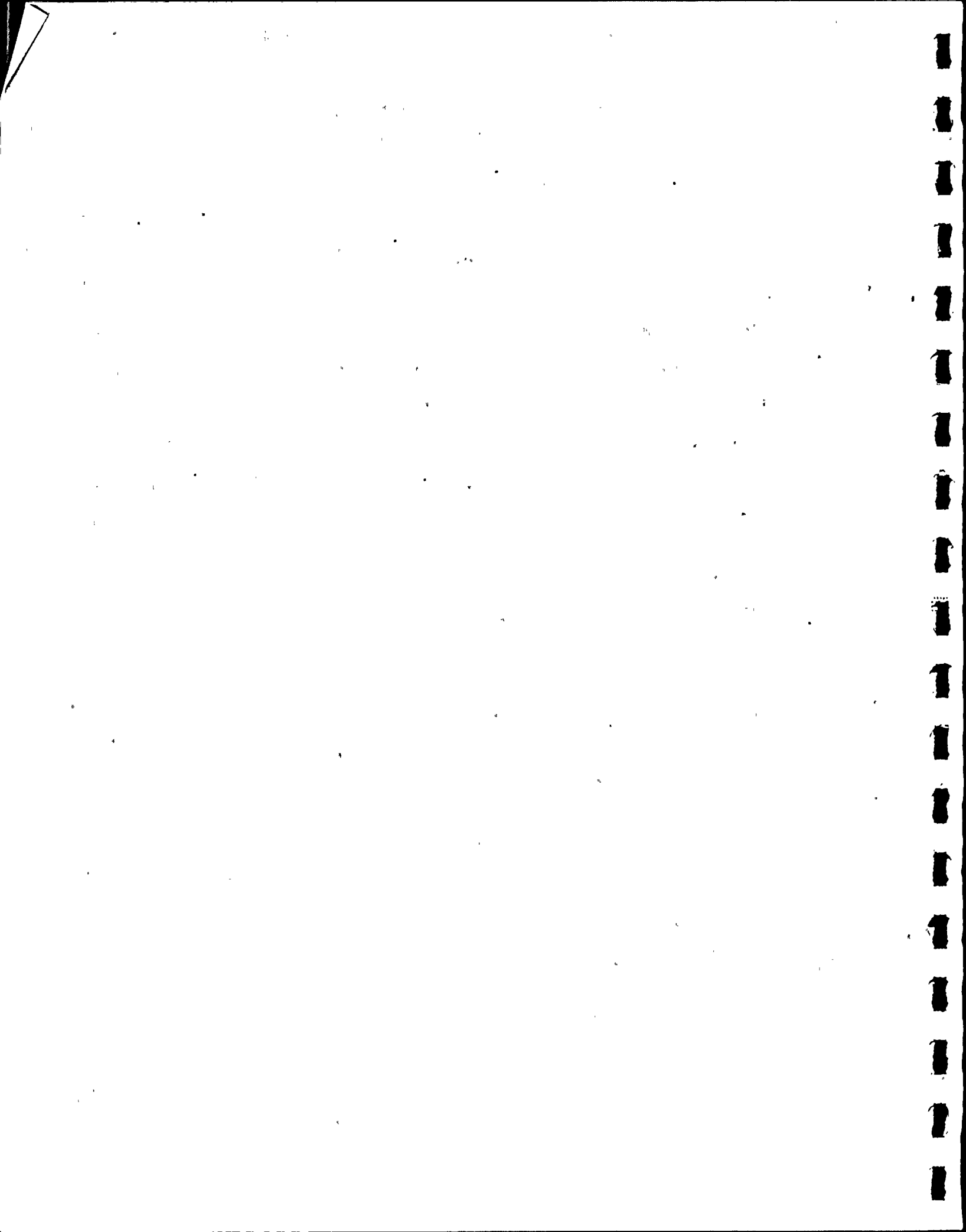
Analysis	Sample Location	Sampling ^(a) Frequency	Specifications	Corrective Action	Notes
Solids: 1. Concentration of Suspended Solids (Crud)	1. Hot Leg Loop 2. PF Inlet	1, S 1, S	Less Than 0.5 ppm ⁽¹⁾ (max. of 2.0 ppm) ^(m)	1. Initiate or Increase Purification Flow. 2. Bleed and feed if no extra purification is available. 3. If maximum limit of 2.0 ppm is exceeded, an orderly shutdown is required.	(1) The abnormal condition of 0.5 to 2.0 ppm is permitted for up to 4 hours to allow for crud burst conditions. (m) Suspended solids level must not exceed 2.0 ppm, the design limit of most major primary components.
2. Total Solids	Reactor Plant Makeup Tank	1	Less Than 0.5 ppm	Bleed and Feed or replace water to reduce solids level.	(n) These will indicate the ability of the filter and IX bed to remove the solids.
3. Activity of Suspended Solids (i)	1. Hot Leg Loop 2. PF Inlet 3. IX Inlet ⁽ⁿ⁾ 4. IX Outlet ⁽ⁿ⁾	1, S 1, S S S	As it relates to E (g)	Initiate or increase purification flow.	
Tritium	1. PF Inlet or Hot Leg Loop 2. Reactor Makeup Water Tank	1 2Y	(g) Concerning Waste disposal		



SPECIFICATIONS AND SURVEILLANCE
CVC:: SYSTEMS

TABLE 1

	<u>Analysis Procedure/Method</u>	<u>Specification</u>	<u>Frequency</u>
A.	<u>Ion Exchangers</u>		
1.	Conductivity/901	(1.)	AS REQUIRED
2.	pH @ 25°C/902	(1.)	AS REQUIRED
3.	Boron/903	DF = 2(min) (2.)(3.)	AS REQUIRED
4.	Chloride/906	0.15 ppm (max)	AS REQUIRED
5.	Fluoride/907	0.1 ppm (max)	AS REQUIRED
6.	Lithium/908	NS	AS REQUIRED
7.	Quantitative Gamma Activity	DF = 10(min) (2) avg	1/M
8.	Dose Rate, Vessel Contact	N.S.	1/M
B.	<u>Filters</u>		
1.	Suspended Solids/911	DF = 10 (min)	1/M
C.	<u>VCT</u>		
1.	Hydrogen/904	9-45 psia	3/W
(1)	Should be consistent with concentrations of chemical additives.		
(2)	DF = influent/effluent.		
(3)	When deborating ion exchanger is operating.		



ATTACHMENT (5)

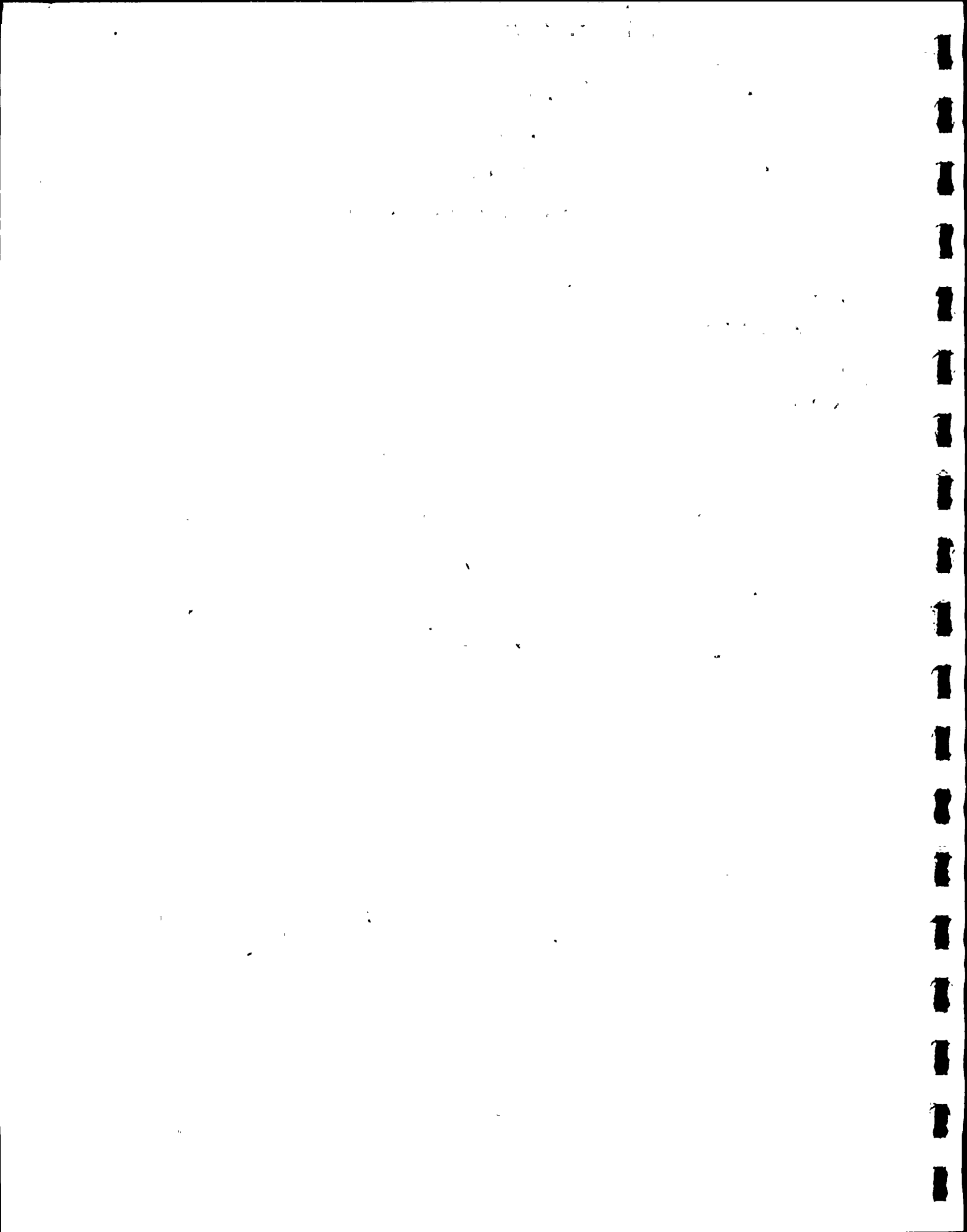
TABLE 1

Reactor Coolant Make Up Pumps Discharge

Analysis

<u>Procedure/Method</u>	<u>Specification</u>	<u>Frequency (1)</u>
1. pH @ 25°C/902	5.8 to 8.0	5/W
2. Conductivity/901	2.0 umho/cm ³ (max)	5/W
3. Chloride/906	0.15 ppm (max)	1/W
4. Sodium/908	10 ppb (max)	1/W
5. Silica/916	0.02 ppm (max)	5/W

1. Samples may be collected from either units reactor coolant make up pump or other suitable sample point off the Demineralized water system.



SPECIFICATION SHEET NO. 2-1

SYSTEM MAKEUP WATER

Analysis	Sample Location	Sampling Frequency	Specifications		Corrective Action	Notes
			Normal	Abnormal		
Conductivity	Makeup Water System De-mineralizer Effluent (MWS Demin. Effluent)	1. Continuous In Line Monitor 2. Daily Grab Sample 3. Prior to putting train on line	<1.0 $\mu\text{mho/cm}$	1.0-2.0 ^(a) $\mu\text{mhos/cm}$	1. Isolate offending train. 2. Perform pH, Cl^- and Conductivity on grab samples from effluent line and from tank that it feeds. 3. Commence Resin Regeneration if out-of-spec condition verified (otherwise, clean cells). 4. Check performance of entire train if water volume since last regeneration is low.	(a) See Section 2.3.2 for further discussion of the out-of-spec condition. Makeup water that exceeds 2.0 $\mu\text{mhos/cm}$ is unacceptable for use.
pH	MWS Demin. Effluent	1. Daily 2. Prior to putting train on line	6.0-8.0	6.0 ^(b) -8.0 ^(c)	1. Isolate offending train. 2. Check performance of entire train if water volume since last regeneration is low. Correct as necessary. 3. If CO_2 is not the problem, commence regeneration.	(b) A pH as low as 5.8 is acceptable only if caused by CO_2 absorption. Boil sample according to Section 6.4.13; Remeasure pH. (c) See Section 2.3.3 for further discussion of the Out-of-Spec condition.

ATTACHMENT (6a)

SPECIFICATION SHEET NO. 2-1

SYSTEM MAKEUP WATER (Continued)

ATTACHMENT (6b)

Analysis	Sample Location	Sampling Frequency	Specifications		Corrective Action	Notes
			Normal	Abnormal		
Chloride	MWS Demin. Effluent	1. Daily Grab Sample 2. Prior to putting train on line	<0.15 ppm	0.15 ^(d) ppm	1. Isolate Offending train. 2. Check performance of entire train if water volume since last regeneration is low. 3. Commence resin regeneration if chloride level verified.	(d) See Section 2.3.4 for discussion of the Out-of-Spec condition.
Fluoride	MWS Demin. Effluent	As required for Primary makeup	<0.1 ppm			
SiO ₂	MWS Demin. Effluent	1. Daily ^(e) Grab Samples	<0.01 ppm	0.01-0.02 ppm ^(f)	1. Isolate Offending train, 2. If analysis confirmed, reduce flow through train. 3. Follow corrective action outlined in Section 2.3.5.	(e) This frequency should be revised at end of preservice period. (f) See Section 2.3.5 for discussion of the Out-of-Spec condition.

F. SECTION IV REFERENCES

1. Combustion Engineering Power Systems. Nuclear Steam Supply System Chemistry Manual CENPD-28. Revision #2.
2. RCP-1-202. Specifications and Surveillance. Reactor Coolant System
3. RCP-1-215. Specifications and Surveillance. Chemical and Volume Control System.
4. RCP-1-201. Specifications and Surveillance. Makeup Demineralized Water.
5. RCP-1-102. Records. Chemical Log 1-102-2. 07/01/80 to 07/31/80.
6. Letter dated 11/08/79. BG&E-10276-70, P. W. Kruse to L. B. Russell
Subject: Calvert Cliffs Unit I Power Distribution Anomaly
Letter dated 11/19/79. BG&E-10276-75, P. W. Kruse to L. B. Russell
Subject: Calvert Cliffs Unit I Power Distribution Anomaly
7. Letter dated 03/07/80. BG&E-10276-99, P. W. Kruse to L. B. Russell
Subject: Calvert Cliffs Unit I Power Escalation Program
8. Memorandum dated 03/11/80. R. F. Eherts to PDTF
Subject: Unit I Power Anomaly
9. Letter dated 12/11/79. BG&E-10276-8, P. W. Kruse to L. B. Russell
Subject: Calvert Cliffs Unit I Power Distribution Anomaly
10. Memorandum dated 01/15/80. A. J. Kaupa to PDTF
Subject: Hydrazine Addition
11. Letter dated 01/15/80. BG&E-10276-88. P. W. Kruse to L. B. Russell
Subject: RCS Hydrazine Addition
12. Letter dated 02/15/80. BG&E-10276-93, P. W. Kruse to L. B. Russell
Subject: Calvert Cliffs Unit I Crud Anomaly
13. Letter dated 12/11/79. BG&E-10276-87, K. W. Kruse to L. B. Russell
Subject: Calvert Cliffs Unit I Power Distribution Anomaly
14. Letter dated 01/19/80. BG&E-10276-87, P. W. Kruse to L. B. Russell
Subject: Volume Control Tank Level
15. Memorandum dated 01/04/80. R. F. Eherts to PDTF
Subject: Discussions with D. Morgan, Combustion Engineering
16. Memorandum dated 02/26/80. R. F. Eherts to J. R. Speciale/PDTF
Subject: Unit I RCS Chemistry
17. Memorandum dated 02/26/80. R. F. Eherts to J. R. Speciale/PDTF
Subject: Unit I Power Anomaly

V. CONCLUSTIONS AND LESSONS LEARNED

Although the evidence is circumstantial, it is reasonable to infer that the reactivity and power distribution anomalies were caused by the slow buildup of crud on the core surfaces. The deposition of crud was preferential to the core top and periphery. The crud was a product of the corrosion of RCS surfaces by slightly higher than normal Oxygen levels in the RCS. The source of the Oxygen was instrument air from an ion exchanger resin flush system. Two inservies values leaked past their seats and increased the Oxygen concentration in the water of the purification section of the CVCS to approximately 300 ppb for several weeks. Although this concentration was further diluted prior to injection back into the RCS, it was apparently enough to overpower the scavenging effect of the Hydrogen in the RCS. Once the conditions for oxidation of RCS surfaces had been established, the normal Oxygen concentration levels in RCS makeup water were enough to maintain that oxidation state even though the original abnormal source of Oxygen had been isolated.

In order to mitigate the effect of Oxygen ingress during this episode and to preclude it from reoccurring in the future, the following short and long term actions have been or are being taken:

- (1) The leaking resin flush valves were repaired.
- (2) The resin flush medium has been changed from air to nitrogen.
- (3) The RCS makeup rate has been reduced by the action of rebuilding a power operated pressurizer relief valve which was a significant source of leakage from the RCS.
- (4) Chemistry procedures have been modified to tighten surveillance at potential sources of air ingress into the RCS.
- (5) Gauges have been added which allow monitoring of any pressure buildup in the nitrogen header supplying the ion exchangers. Although it is not expected that the introduction of nitrogen to the RCS would result in an anomaly such as that caused by Oxygen, the monitoring of header pressure provides an extra measure of conservatism to prevent the inadvertant introduction of insoluble gas to the RCS.

- (6) Hydrazine in stoichiometric concentrations is metered into the RCS makeup water at the point of its injection into the CVCS. A control scheme is being developed to automate this process.
- (7) Pertinent core and fuel performance parameters are being trended and the surveillance and evaluation frequency has been increased.
- (8) The feasibility of deaerating the RCS makeup water is being investigated.
- (9) A fuel inspection program for the purpose of documenting any lasting effects of the episode is being developed for performance at the next refueling.

APPENDIX A

CHEMISTRY RESULTS OF THE UNIT 1 HYDROGEN PEROXIDE TREATMENT

I. DISCUSSION

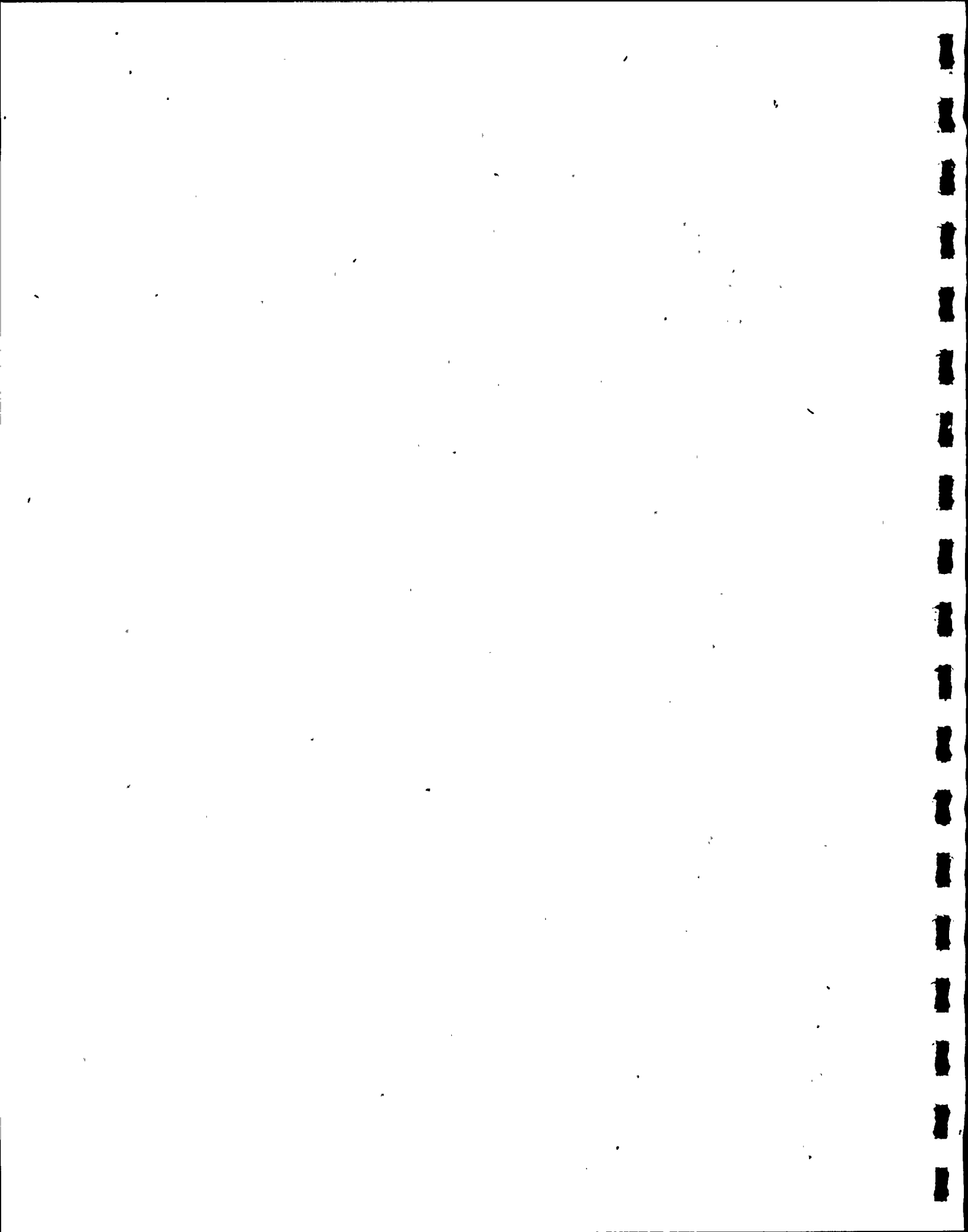
On January 27, 1980, hydrogen peroxide was added to the Unit 1 reactor coolant system and various chemistry parameters were monitored in order to determine the effectiveness of the expected chemical shock to the system. Hydrogen peroxide has been added to a number of other nuclear facilities and an EPRI report has been published which documents the findings of a limited survey of utility experience and the results of two intensive test programs (reference 1). The pertinent findings of that report were:

1. Greater than 90% of the Co-58 activity in the primary coolant is nonfilterable subsequent to the peroxide injection or oxygenation.
2. In-core deposits are the major source of the activity released during shutdown with or without peroxide injection.
3. Peroxide or oxygen addition had no major impact on primary system shutdown radiation fields.
4. Oxygenation and hydrogen peroxide addition produce similar effects on the release of Co-58. This results from the interrelationship of oxygen and hydrogen peroxide caused by radiolytic effects in the core.
5. Since Co-58 is present predominantly as a nonfilterable species subsequent to oxygenation or the addition of hydrogen peroxide, neither dropout nor the high radiation fields associated with dropout would be expected to occur.

The main purpose for performing the hydrogen peroxide treatment on Unit 1 was to affect a chemical shock to such a degree that an improvement in core differential pressure would be manifested. It should be pointed out that the EPRI report concluded that the hydrogen peroxide technique, "can be of significant value in eliminating the occurrence of significant releases when purification to reduce refueling platform manpower exposures would impact on the refueling outage schedule". Although Ft. Calhoun observed improvement in reactor coolant flow as an apparent result of the hydrogen peroxide technique (reference 2), the EPRI work did not address any effects relative to possible core parameter improvements. There is, therefore, no other evidence that the hydrogen peroxide treatment will result in a decrease in core differential pressure.

II. PLANT PROCEDURE FOR HYDROGEN PEROXIDE ADDITION

A plant procedure was prepared for the hydrogen peroxide treatment (reference 3). The procedure delineated the initial conditions



required, the collection of baseline data, the addition of the peroxide and the sampling/surveillance program needed to monitor the effectiveness of the addition on the reactor coolant system chemistry. Of crucial importance was the performance of the chemical and volume control ion exchangers. The ion exchangers were needed to control the expected high coolant activity which would result from the solubilization of the Co-58 isotope and also control other corrosion products.

In order to determine the endpoint of the hydrogen peroxide addition certain chemistry parameters needed to be monitored carefully after each addition. The plants in the EPRI study appeared to monitor Co-58 activity increases after peroxide additions as a primary parameter. In addition, oxygen and hydrogen peroxide levels were considered useful in determining the endpoint. The decision was made to terminate hydrogen peroxide injections when there was an inability to produce an "effective" chemical shock as determined by suspended solids, oxygen, and Co-58 activity. Therefore, a combination of these parameters would be utilized to determine the endpoint for the additions.

Another aspect of the procedure considered important was the operation of the reactor coolant pumps. It was decided that the peroxide would first be added to the loop from which letdown was being withdrawn. Therefore, 12A and 12B pumps would remain in service during and following the first addition and then the other loop would be flushed by switching to one pump per loop operation. By operating the pumps in this manner flushing of the core and steam generator surfaces would be more effective and purification could then be employed for removal of soluble and insoluble crud.

III. RESULTS

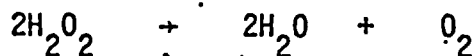
A. Chronology of Events

Table 1 consists of a chronology of events before, during, and after the peroxide addition. Of particular note is the venting and repressurization of the volume control tank (VCT) with nitrogen prior to shutdown in order to reduce the hydrogen in the coolant to a level corresponding to the lower end of the normal operating concentration, (i.e., 10-50 cc hydrogen/kg water). Following shutdown, degassification continued until hydrogen was less than 5 cc hydrogen/kg water.

The increased rate by which the hydrogen was successfully lowered may be attributed to a lowering of the normal operating band of the VCT water level. This increased the efficiency of gas stripping in the VCT vapor. Also of note from Table 1 are the periodic changes in the reactor coolant pump operation. As mentioned earlier this was accomplished intentionally in order to insure a high degree of effectiveness from the peroxide additions.

B. Peroxide Additions

A total of 15.1 liters of hydrogen peroxide was added to the reactor coolant system within approximately 9 hours. Table 2 lists the peroxide additions and gives a comparison of theoretically calculated oxygen levels with observed oxygen levels based on the overall decomposition reaction:



The data shows that the last peroxide addition resulted in close to predicted oxygen levels indicating that equilibrium had been reached.

C. Effects on Chemistry

Figure 1 is a plot of the Co-58 activity, Co-60 activity, and Co-58/Co-60 ratio during the peroxide additions. Figure 2 is a plot of other chemistry data collected. The peroxide additions are highlighted by arrows at the times the addition was completed.

The addition of the hydrogen peroxide resulted in significant changes in the chemistry of the reactor coolant system. Of particular note were the increases of Co-58 total activity and suspended solids. As expected, the increase in solubility of cobalt and nickel oxides present in the crud caused high dissolved Co-58 activity levels and the sudden shock on converting the chemistry from a reducing environment to an oxidizing environment caused crud to spall off system surfaces as indicated by the increase in crud levels. The resulting oxygen levels reflect the addition of the peroxide and appear to show that consumption of the oxygen occurred while conversion of the oxides to soluble forms took place.

The criteria for termination of the hydrogen peroxide addition to the reactor coolant system was based on several parameters. One of the critical parameters monitored was the oxygen level in the reactor coolant system. The oxygen level showed a decrease in a short time following the first addition showing that the system had not yet come to an equilibrium. At 2040 hrs., following the second addition, the oxygen level was .25 ppm, while the next or final injection brought the oxygen level up to 1 ppm. This level was close to predicted and indicated that oxygen was essentially at equilibrium (Table 2). The next sample at 2400 hrs. showed a constant level of oxygen of 1 ppm. In addition to the oxygen parameter, suspended solids and Co-58 levels had peaked earlier and showed a slight decreasing trend which was expected because of the small purification flow rate of 40 gallons per minute. Peroxide additions were therefore terminated at 0020 hrs. on 1/28/80.

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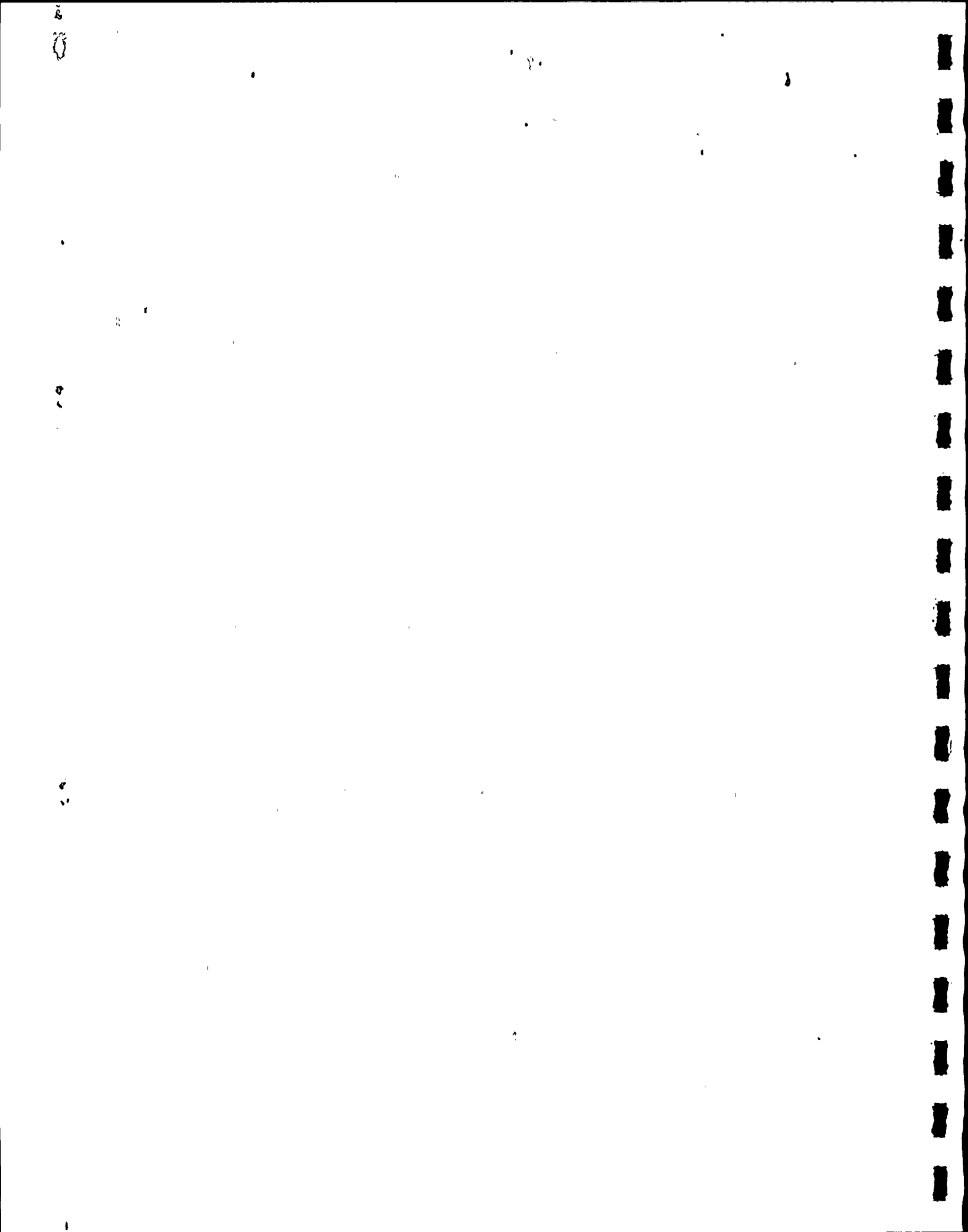
Reference (1) concluded that in-core deposits were the major source of the activity released during shutdown. The addition of hydrogen peroxide to Unit 1 appear to confirm that conclusion. Reference (1) showed that the average Co-58/Co-60 ratio of crud deposited on steam generator diaphragms was significantly lower than the ratio observed during the release of crud following peroxide addition. This was attributed to increasing solubility of crud on core surfaces vice out-of-core surfaces. Table 3 shows the results of smears taken from Unit 1 and Unit 2 steam generator diaphragms. Figure 1 shows the ratio of Co-58 to Co-60 during and following the peroxide additions. The data shows that Co-58/Co-60 ratio following the peroxide addition was about 200 whereas the steam generator diaphragm typical ratio is considerably lower. These results appear to confirm that the majority of the crud observed in the reactor coolant system following the peroxide addition to Unit 1 came from in-core surfaces.

D. Reactor Coolant System Cleanup

During the addition of peroxide letdown flow was approximately 40 gpm. At 1400 hrs. on 1/28/80, flow was increased to a nominal 120 gpm to more rapidly affect cleanup. During these periods two purification ion exchangers were in service. They consisted of a cation removal ion exchanger and a mixed bed (cation and anion removal) ion exchanger. Both ion exchangers were utilized in series operation. Table 4 shows the Co-58 decontamination factors (DF's) determined across the ion exchangers at various times.

Cleanup of the reactor coolant system while utilizing reactor coolant pump operation continued until about 2000 hrs. on 1/29/80 when draining of the system was started. After that time the shutdown cooling system remained in-service to continue to remove soluble Co-58 and suspended solids.

During the peroxide addition, Co-58 levels increased to $2 \mu\text{Ci/cc}$ as opposed to the baseline data of $6 \times 10^{-3} \mu\text{Ci/cc}$ and the normal shutdown levels of 4×10^{-1} to $8 \times 10^{-1} \mu\text{Ci/cc}$. The system was not allowed to be opened or drained down in order to allow a cleanup of the system to baseline levels. This was to insure that the radiation levels of the system components would not be higher than normal due to a possible redistribution of the crud. Purification was maintained until the Co-58 levels returned to normal shutdown cooling levels and the system was not experiencing additional crud releases while alternating reactor coolant pump operation. The decreasing trend in suspended solids, except for a small crud release and corresponding increase in Co-58 activity levels at 0800 on 1/29/80, indicated that cleanup was effective. The 12 hour period on 1/29/80 from 0800 to 2000 hrs. indicated that the system chemistry was continuing to trend down to normal shutdown levels. Therefore normal shutdown conditions had been achieved and the draining of the system could begin. In addition, shutdown radiation levels were showing a continuing downward trend towards normal shutdown levels.



It has been estimated that from the period 1510 hrs. on 1/27/80 thru 1400 hrs. on 1/28/80, 282 curies of Co-58 were removed from the coolant. This assumed a nominal flow rate of 40 gpm. From 1400 hrs. on 1/28/80 thru 2000 hrs. on 1/29/80, 291 curies of Co-58 were removed at a nominal flow rate of 120 gpm. Therefore the total Co-58 activity removed from the coolant starting with the peroxide addition until draining of the coolant was initiated was 573 Curies.

E. Effects on Shutdown Radiation Levels

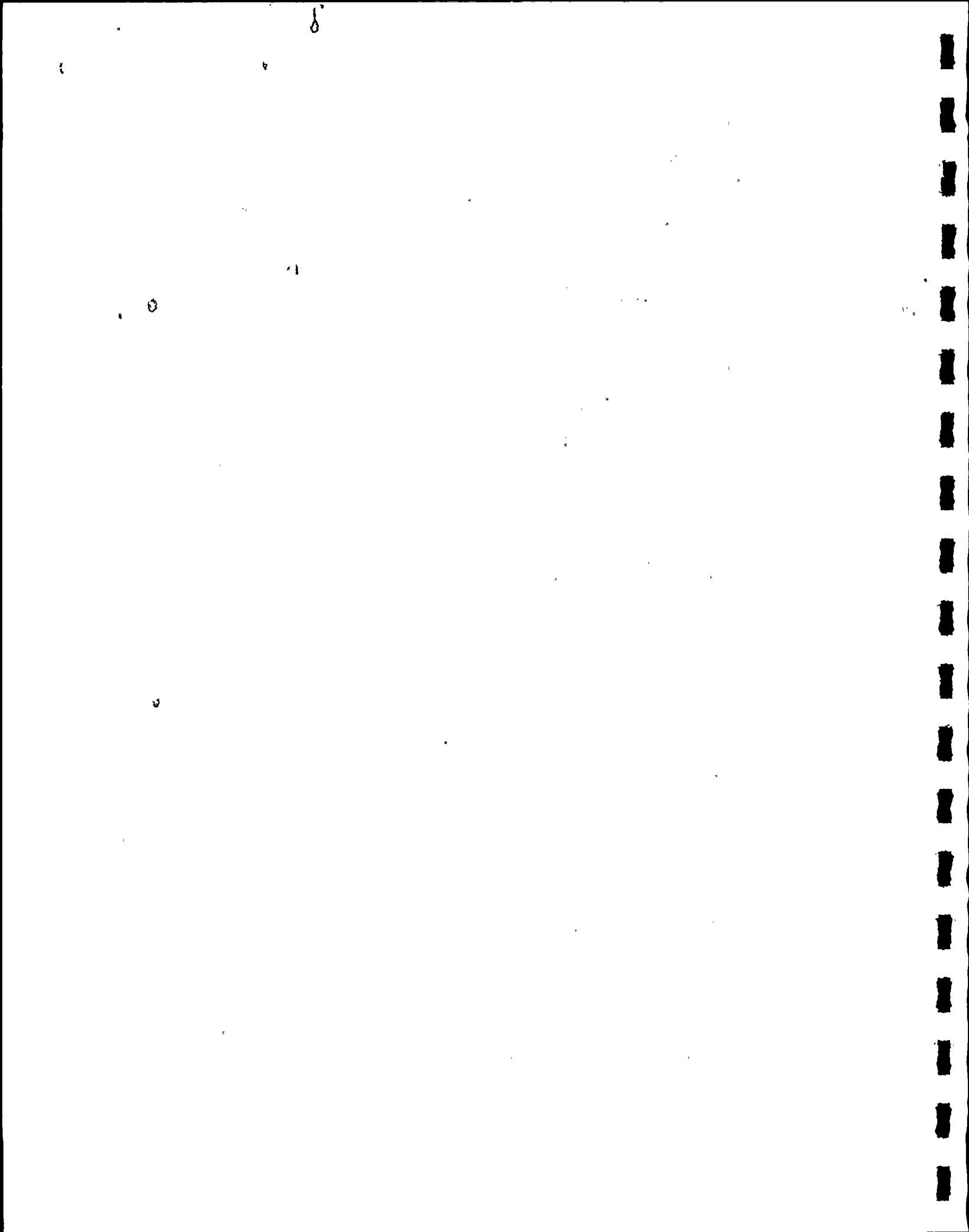
During and following the peroxide addition several areas were selected in the plant for intensive radiation level monitoring. The following locations were selected:

1. #12 Purification Ion Exchanger
2. Valve 1-SI-306 (Outlet flow control valve on safety injection)
3. #11 and #12 Shutdown Cooling (SDC) Heat Exchangers
4. #11A and #11B Cold Leg

#12 Purification Ion Exchanger was monitored in order to determine when it should be removed from service since the radiation level is a critical parameter with respect to use of shipping casks for ultimate disposal of the resin. The ion exchanger reached a peak radiation level of 600-900 R/hr about 1½ days following the last peroxide addition and it was then removed from service.

The radiation levels at the other locations are shown in Figure 3. The radiation levels monitored at SI-306 and the SDC heat exchangers show maximum readings near the times of the peroxide additions. This appears to reflect the crud release which occurred at that time. The radiation levels at #11A and #11B cold leg do not appear to reflect the crud release, however, there is a gradual decrease in radiation levels at those locations and may be an indication of the clean-up of the system.

Historical data regarding previous radiation levels at these locations appear to support the fact that the dose rates shown in Figure 3 existed before without the peroxide treatment. Dose rates up to 350 mR/hr on the SDC heat exchangers have been experienced during previous shutdowns as well as dose rates of about 150 mR/hr on #11A cold leg. SI-306 dose rates have generally averaged about 60 mR/hr during previous shutdowns which is close to the average dose rate experienced following the peroxide treatment.



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F. Effects on Core Differential Pressure

The addition of hydrogen peroxide to the Unit 1 reactor coolant system appears to be responsible for the reduction of the core differential pressure observed following heat-up on February 11, 1980. Figure 4 shows the various core parameters monitored and their respective values prior to, and after the hydrogen peroxide chemical shock. Core Δp dropped from 15.7 psi to 13.8 psi or about a 12% reduction.

Based on the results of the hydrogen peroxide treatment the following summary is given:

1. The hydrogen peroxide chemical shock appears to have reduced core differential pressure by 12%.
2. A total volume of 15.1 liters of hydrogen peroxide was added to the RCS in three separate injections.
3. Increases in total Co-58 activity and suspended solids indicate the hydrogen peroxide produced a significant crud release.
4. Based on a comparison of data collected here with the results of the EPRI study, in-core deposits appeared to be the major source of activity released.
5. Approximately 600 Curies of Co-58 was removed from the coolant during and following the hydrogen peroxide treatment.
6. Peroxide additions did not cause unexpected changes in shutdown radiation fields.

TABLE 1

CHRONOLOGY OF EVENTS FOR H₂O₂ TREATMENT OF U-1 RCS

1/25/80	0830 hrs.	RCS Hydrogen 18.2 ccH ₂ /kg H ₂ O
	2000	Vented & Repressurized VCT w/N ₂
	2105	Vented & Repressurized VCT 4 times w/N ₂
	2120	Commenced Reducing Power for Shutdown
	2357	Opened TG Output
1/26/80	0110 hrs.	Stop 12A & 12B RCP
	0150	Commenced Cooldown
	0200	RCS Hydrogen 13.5 ccH ₂ /kg H ₂ O
	0245	Started 12B RCP Stop 11B RCP
	0400	RCS Hydrogen 7.8 ccH ₂ /kg H ₂ O
	0446	In Mode 4
	0600	RCS Hydrogen 4.5 ccH ₂ /kg H ₂ O
	0700	Secured Degassing VCT; Filled & Vented 4 times
	0920	Stop 11A & 12B RCP's
	0925	Start SDC with 11 LPSI
	0936	Restart 11A & 12B RCP's
	1215	In Mode 5
	1343	Start LPSI Pump on SDC
	1720	Completed Press & Vent VCT
1/27/80	0220 hrs.	Removed #11 purif ion exchanger from service, #12 purif into service #11 deborating in service
	0635	Start 12A RCP Stop 11A RCP
	0854	Stop 12B RCP Start 11B RCP

TABLE 1 (CONT'D)

1/27/80	1035	Stop 12A RCP Start 12B RCP
	1225	Stop 11B RCP Start 12A RCP
	1250	Started addition of 9.1 Liters of Hydrogen Peroxide
	1415	Completed add of Hydrogen Peroxide to RCS
	1736	Stop 12A RCP, Start 11B RCP
	1746	Started Addition of 2.0 Liters Hydrogen Peroxide to RCS
	1816	Stop 12B RCP Start 12A RCP
	1835	Completed add of Hydrogen Peroxide
	2058	Stop 11B RCP Start 12B RCP
	2110	Started Addition of 4.0 Liters Hydrogen Peroxide to RCS
	2155	Completed add of Hydrogen Peroxide to RCS
1/28/80	1030	Stop 12A RCP Start 11B RCP
	1315	Start 13 Charging Pump (11 Already Running)
	1335	Start 12 Charging Pump
	1400	Increased Purif. Flow to ~120 gpm
	1530	Completed Collection of Suspended Solids Sample for Chemical Analysis
	1830	Stop 11B RCP Start 12A RCP
1/29/80	0230	Started 11B RCP Stop 12A RCP
	1030	Start 12A RCP Stop 11B RCP
	1125	Remove 12 purif IX from service and placed 11 Deborating IX & 11 Purif IX In Series
	1151	Stop all RCP's

TABLE 1 (CONT'D)

1/29/80	1248	Start 11B RCP
	1252	Start 12A RCP
	1825	Start 12B RCP Stop 11B RCP
	2150	Stop 12A & B RCP
	2155	Stop SDC Flow Thru IX
	2200	Stop 12 & 13 Charging Pump
	2220	Stop 11 Charging Pump
	2233	Start 11 Charging Pump
1/30/80	0200	Stop 11 LPSI
	0630	Purification on SDC

TABLE 2

THEORETICAL VERSUS OBSERVED OXYGEN LEVELS

FOLLOWING HYDROGEN PEROXIDE ADDITIONS

<u>ADDITION TIME</u>	<u>VOLUME ADDED(LITERS)</u>	<u>THEORETICAL OXYGEN(PPM)</u>	<u>OBSERVED OXYGEN(PPM)</u>	<u>RATIO THEORETICAL/OBSERVED</u>
1415	9.12	1.57	0.100	15.7
1835	2.0	0.76	0.250	3.04
2155	4.0	1.52	1.00	1.52

TABLE 3

TYPICAL Co-58/Co-60 RATIOS FROM
STEAM GENERATOR DIAPHRAGMS

<u>UNIT 1</u>	<u>Co-58/Co-60 ACTIVITY(uCi)</u>	<u>Co-58/Co-60 RATIO</u>
Outage #2	2.38E-1/1.30E-1	1.8
Outage #3	5.26E-1/1.29E-1	4.1
<u>UNIT 2</u>		
Outage #1	6.89E-1/7.48E-2	9.2
Outage #2	7.44E-1/8.78E-2	8.5

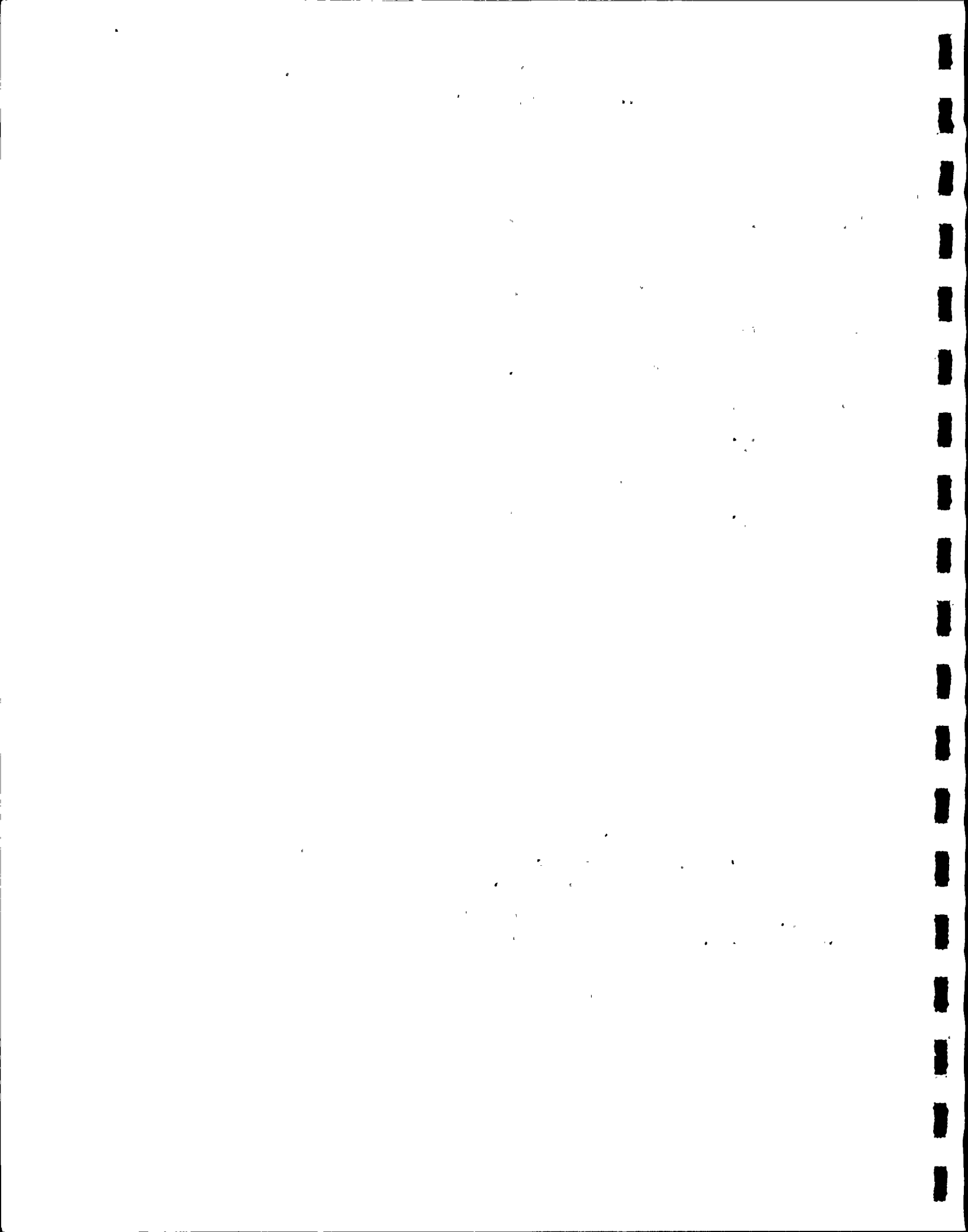
TABLE 4

Co-58 DECONTAMINATION FACTORSCo-58 Activity ($\mu\text{Ci/ml}$)

<u>DATE</u>	<u>TIME</u>	<u>INLET</u>	<u>OUTLET</u>	<u>DECONTAMINATION FACTORS¹</u>
1/27	0247	4.7 E-1	6.6E-4	712
1/27	1800	1.54	8.5E-4	1812
1/28	0800	1.17	4.3E-4	2720
1/28	1600	8.1 E-1	2.3E-3	352
1/28	2000	4.5 E-1	3.5E-3	128
1/28	2400	3.3 E-1	7.8E-3	42
1/29	0800	1.2 E-1	2.8E-3	43
1/29	1145	2.3 E-1	1.3E-3	177 ²
1/29	2000	1.3 E-1	4.9E-3	26 ²

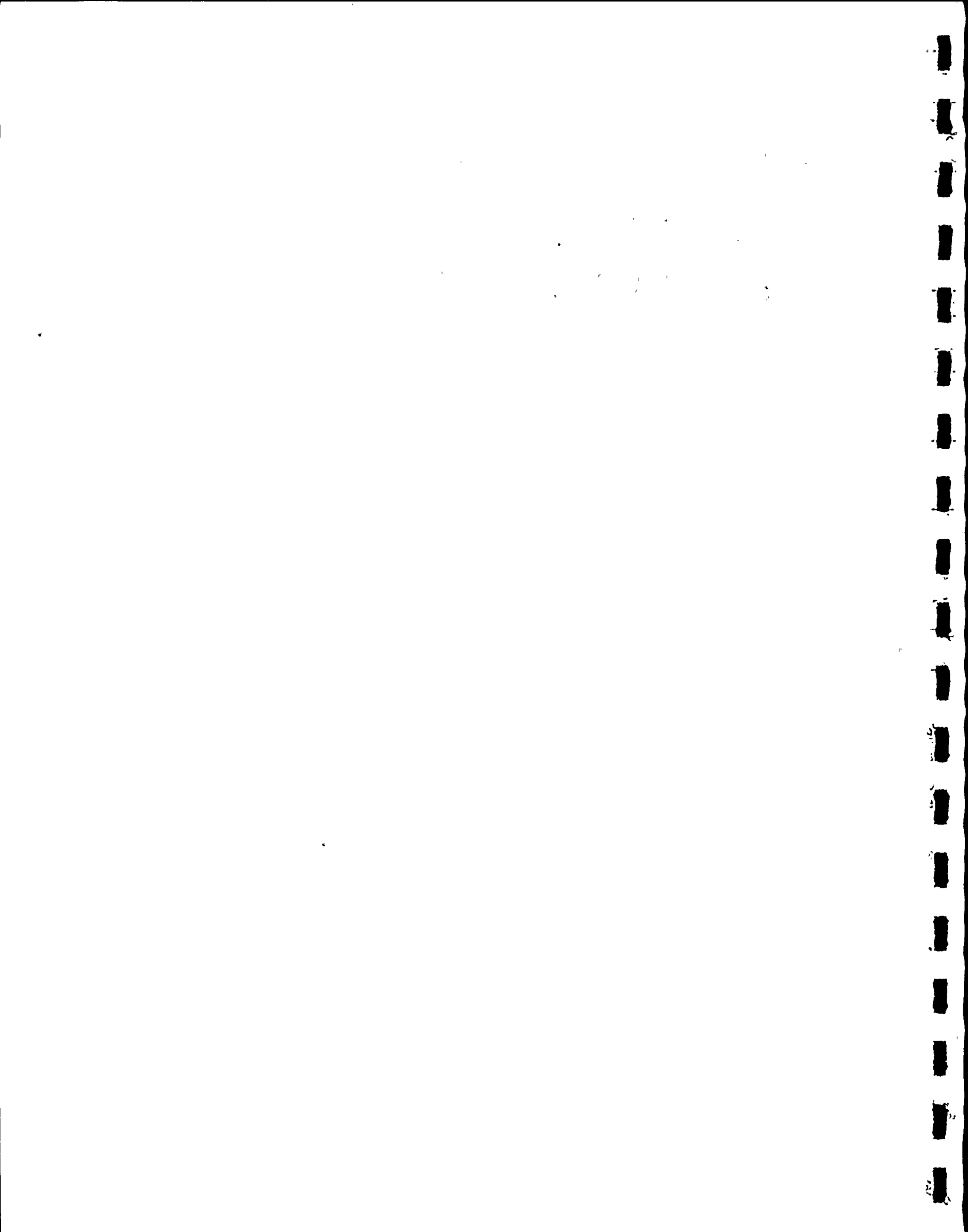
¹ Decontamination factors were taken across #12 purification ion exchanger (cation) and #11 deborating ion exchanger (mixed bed) in series operation

² #12 purification ion exchanger removed from service and #11 purification ion exchanger (cation) placed in service at 1125 hrs. on 1/29/80,



REFERENCES

1. EPRI Report NP-692, "Effects of Hydrogen Peroxide Additions on Shutdown Chemistry Transients at Pressurized Water Reactors", April 1978
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READ TO CHECKS BY

SCHAFFNER, RICHARD

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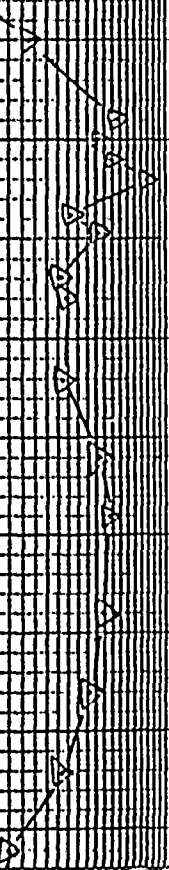
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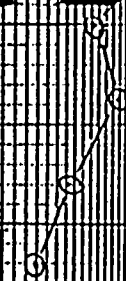
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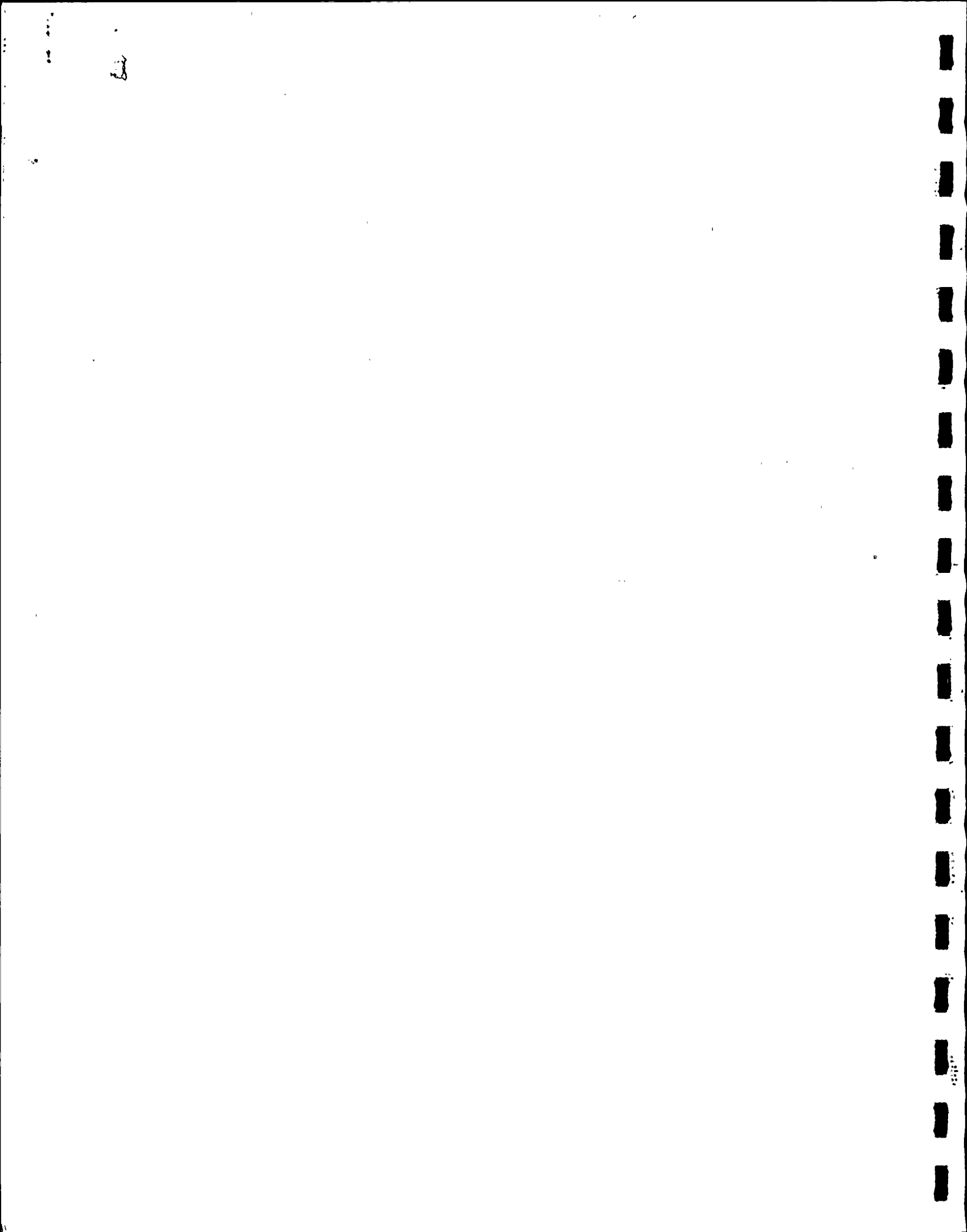


FIGURE 3
EFFECTS ON SHORTWAVE RADIATION FIELDS

