CALVERT CLIFFS UNIT I
CYCLE 4

June, 1980

REPORT OF POWER DISTRIBUTION EPISODE
October 1979 - May 1980

8008190373

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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 diagnositic 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 determing 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 improvment exceeded the most optimistic predictions. Therefore, contingency plans for continuing the decrudding 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, isothermal 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	~.003 μc/cc
I 133	~.03 μc/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	~.003 μc/cc
I - 133	~.03 μc/cc

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

CORE PARAMETERS
UNIT-1, CYCLE 4

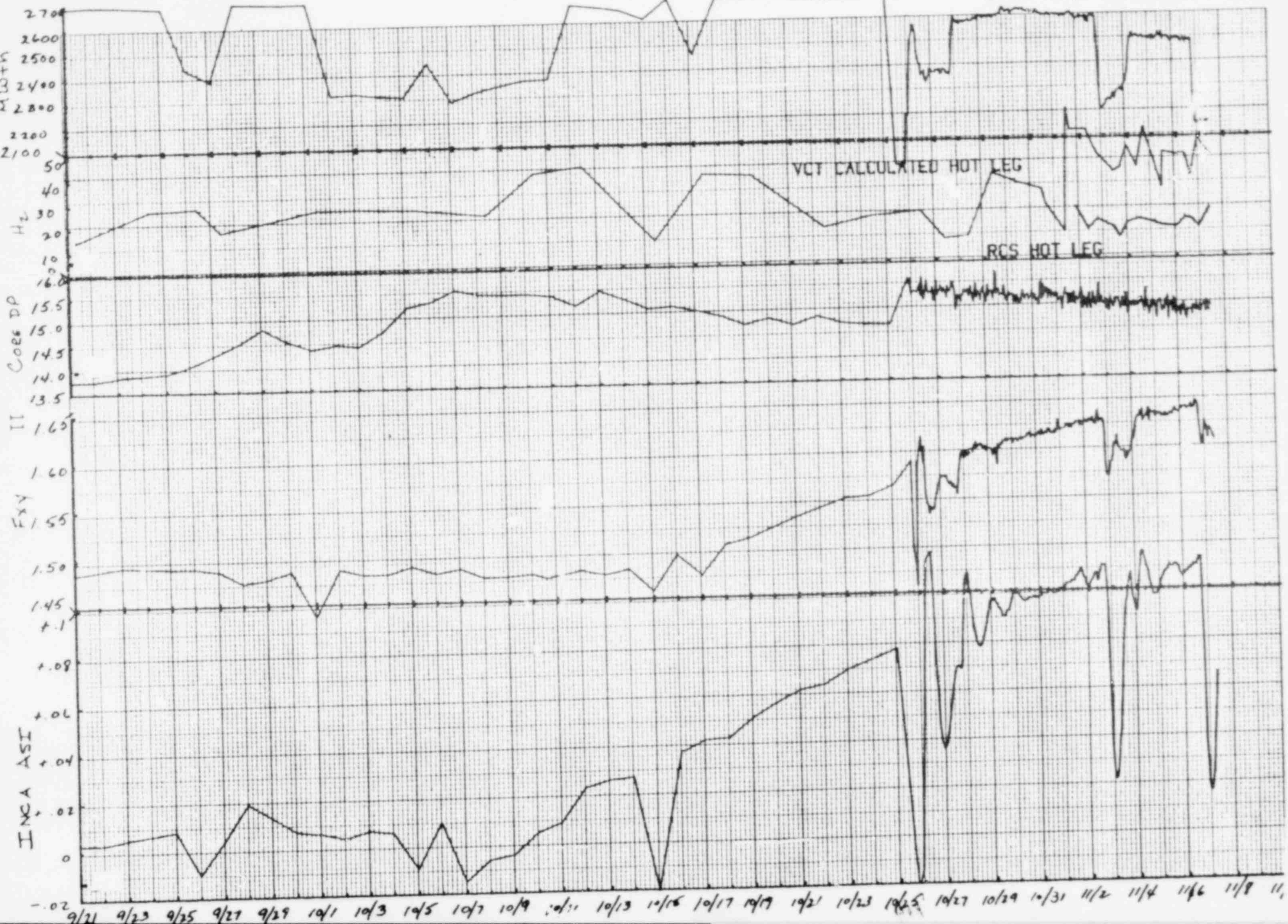


FIGURE II.1

FIGURE II.2

CORE PARAMETERS
UNIT-1, CYCLE 4

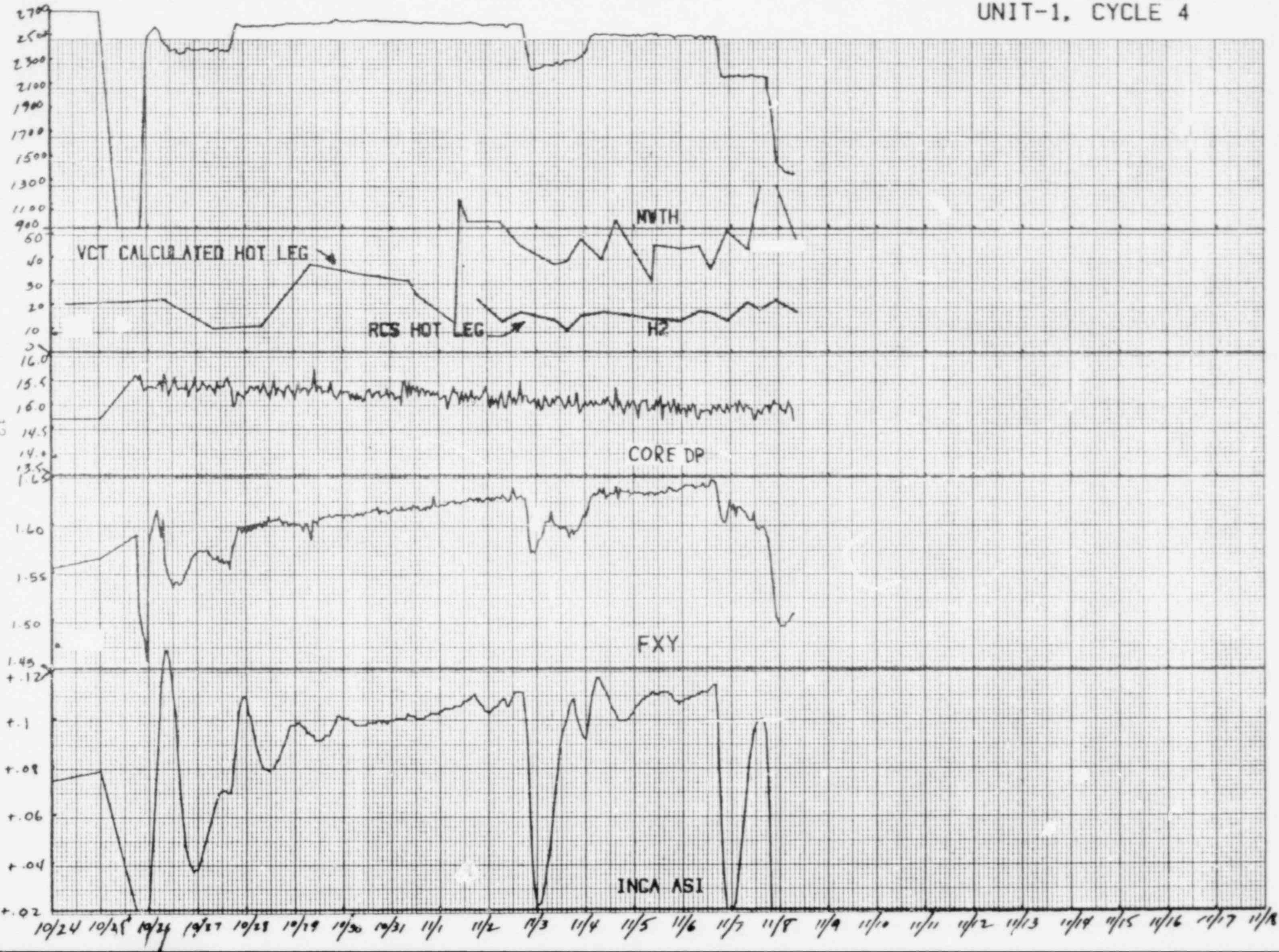
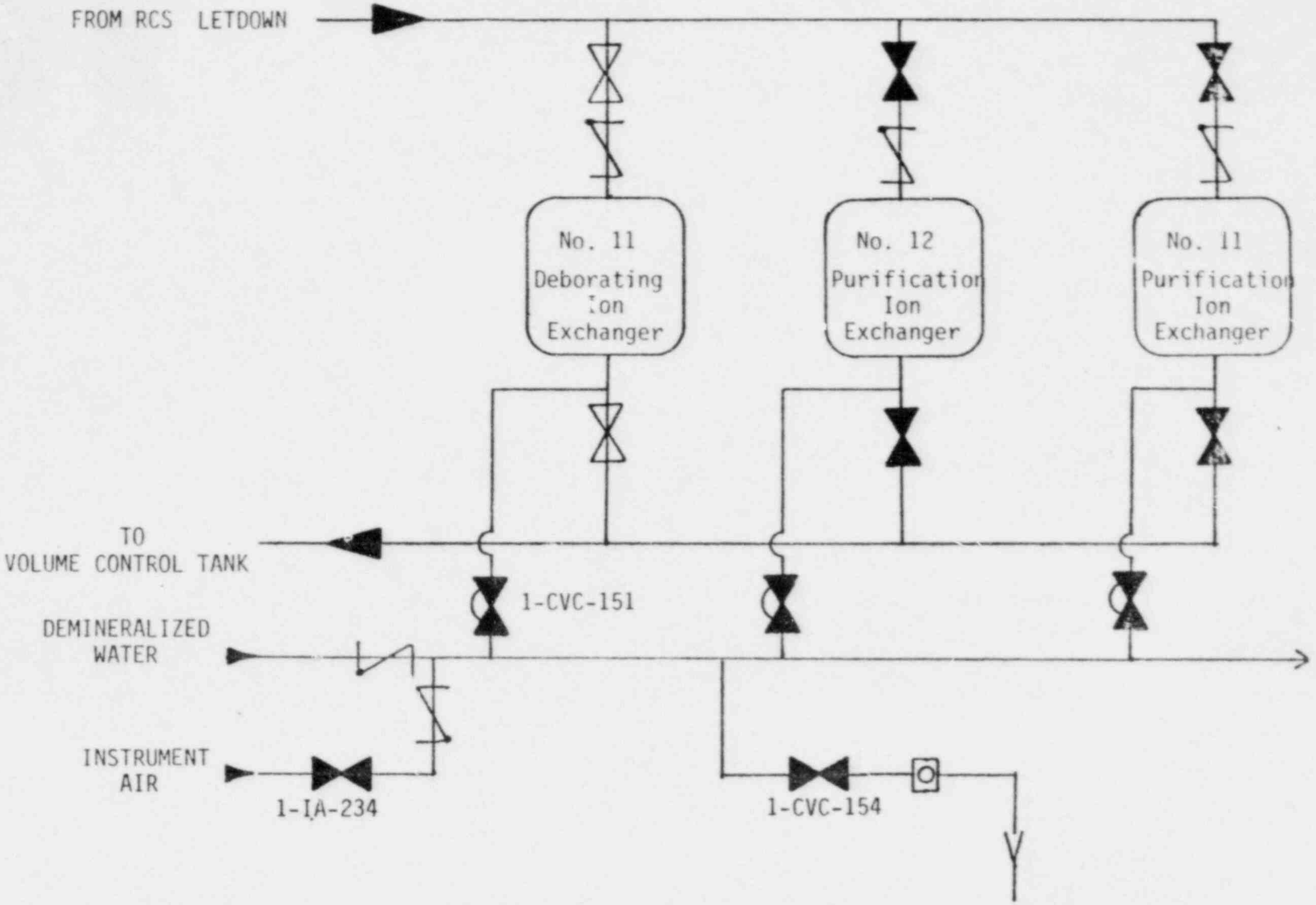


FIGURE II.3



11/11/79 RG

FIGURE II.4

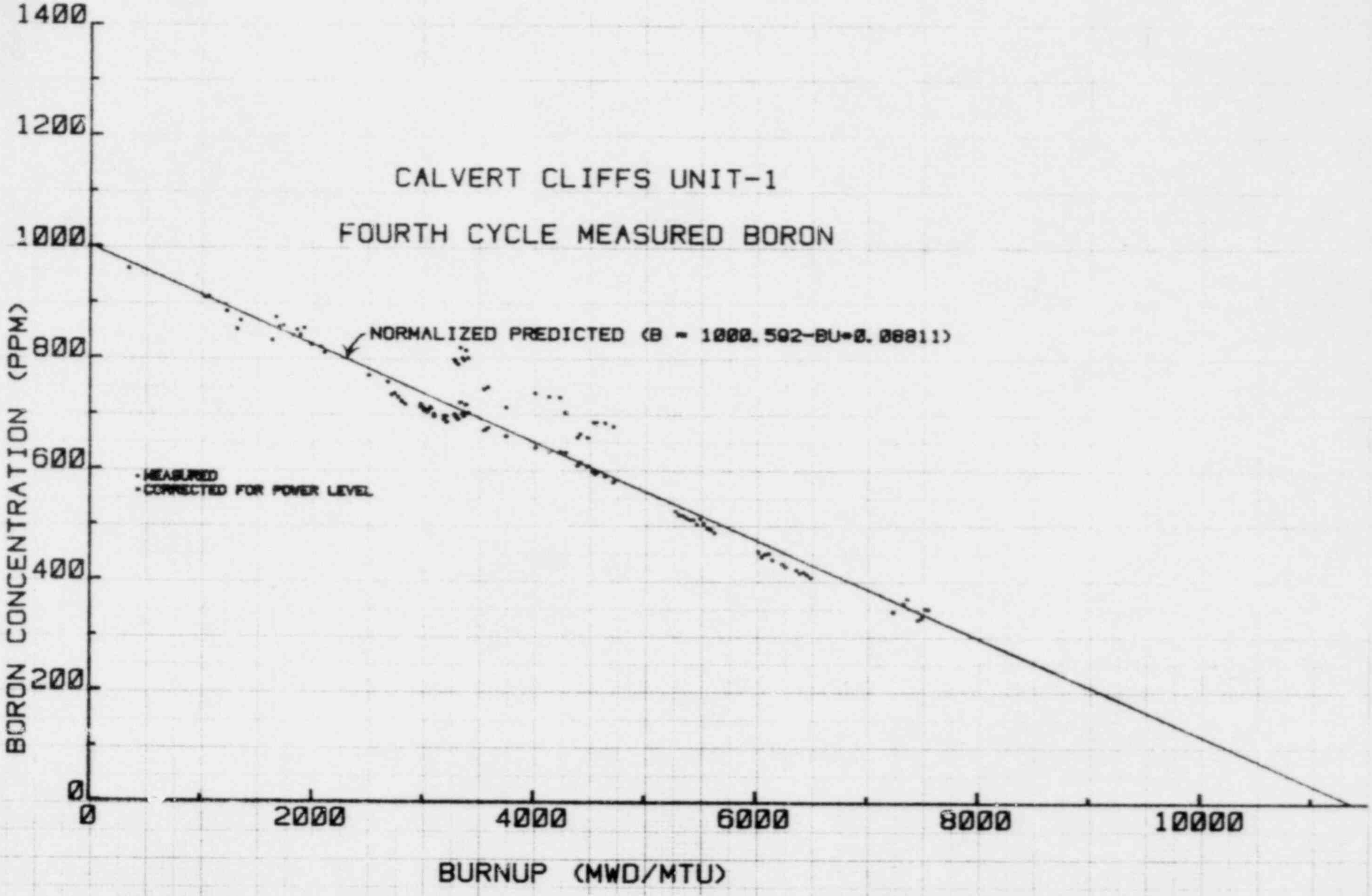
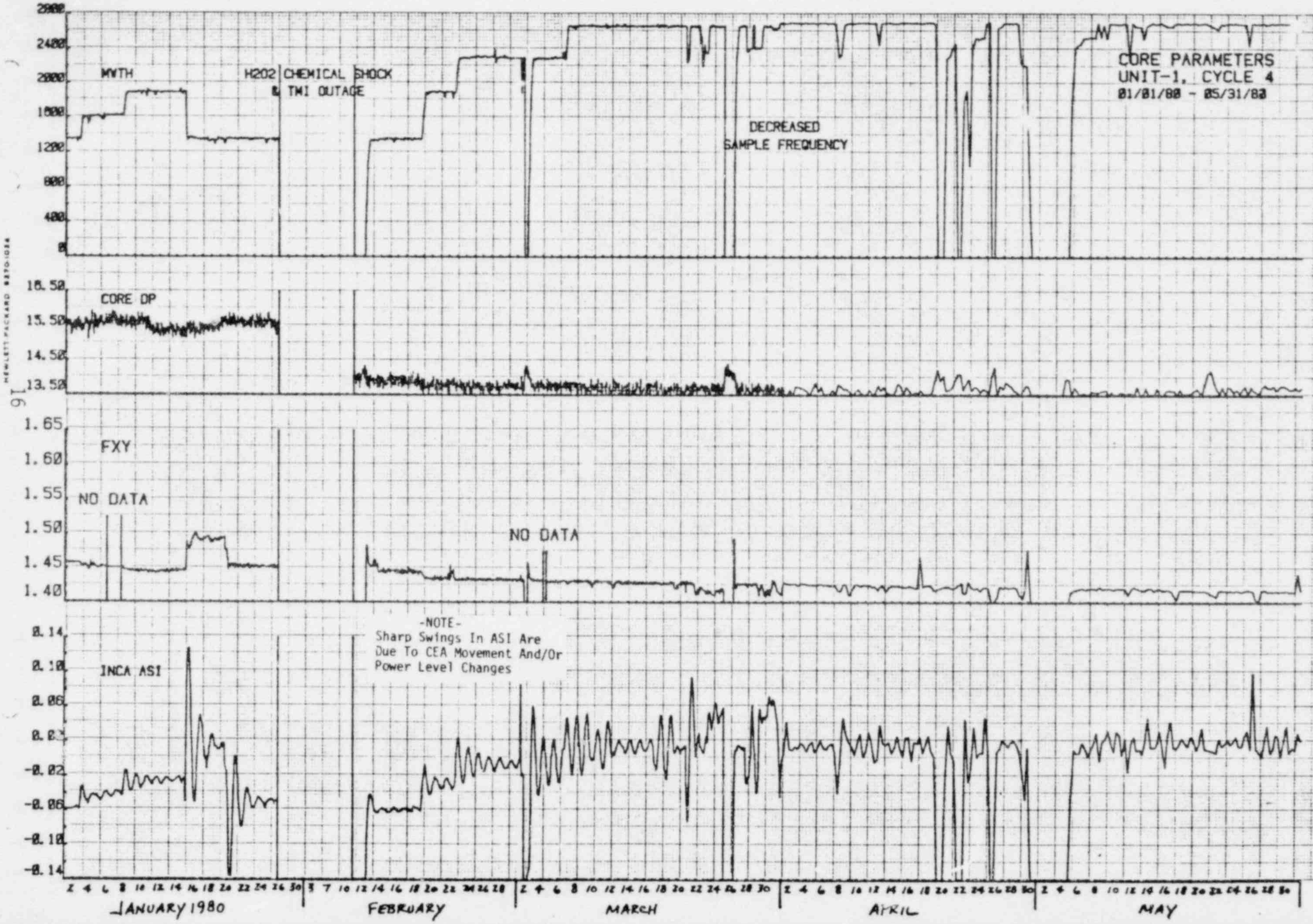

CALVERT CLIFFS UNIT-1
FOURTH CYCLE MEASURED BORON
NORMALIZED PREDICTED (B = 1000.592-BU*0.08811)
· MEASURED
· CORRECTED FOR POWER LEVEL
BORON CONCENTRATION (PPM)
1400
1200
1000
800
600
400
200
0
0
2000
4000
6000
8000
10000
BURNUP (MWD/MTU)

FIGURE II.5


CORE PARAMETERS
UNIT-1. CYCLE 4
09/21/79 - 02/27/80
H202 CHEMICAL SHOCK & TMI OUTAGE
INCREASED SAMPLE FREQUENCY
MWTH
2800
2400
2000
1600
1200
800
400
0
CORE DP
16.50
15.50
14.50
13.50
FXY
1.65
1.60
1.55
1.50
1.45
1.40
NO DATA
NO DATA
INCA ASI
0.14
0.10
0.06
0.02
-0.02
-0.06
-0.10
-0.14
-NOTE-
Sharp Swings In ASI Are Due To CEA Movement And/Or Power Level Changes
DECEMBER
JANUARY 1980
FEBRUARY

FIGURE II.6


CORE PARAMETERS
UNIT-1, CYCLE 4
01/01/80 - 05/31/80
MVTH
H2O2 CHEMICAL SHOCK
& TMI OUTAGE
DECREASED
SAMPLE FREQUENCY
CORE DP
FXY
NO DATA
NO DATA
INCA ASI
-NOTE-
Sharp Swings In ASI Are
Due To CEA Movement And/Or
Power Level Changes
2800
2400
2000
1600
1200
800
400
0
16.50
15.50
14.50
13.50
1.65
1.60
1.55
1.50
1.45
1.40
0.14
0.10
0.06
0.02
-0.02
-0.06
-0.10
-0.14
2 4 6 8 10 12 14 16 18 20 22 24 26 30
3 7 10 12 14 16 18 20 22 24 26 28
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
JANUARY 1980
FEBRUARY
MARCH
APRIL
MAY

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-demensional 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 CEPAK 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.

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 [ ] 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.

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 dipicted 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. During the event, the measured coefficients were about 0.30 to 0.40 x 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 x 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 of 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 crudding 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 [illegible]/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 mg/cm^2 of crud (25% Ni, 48% Fe, 27% O) on the cladding or a plating of more than 0.05 mgB_{nat}/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.

FIGURE III.1

Calvert Cliffs I Cycle 4

Reactivity Defect vs Power Level

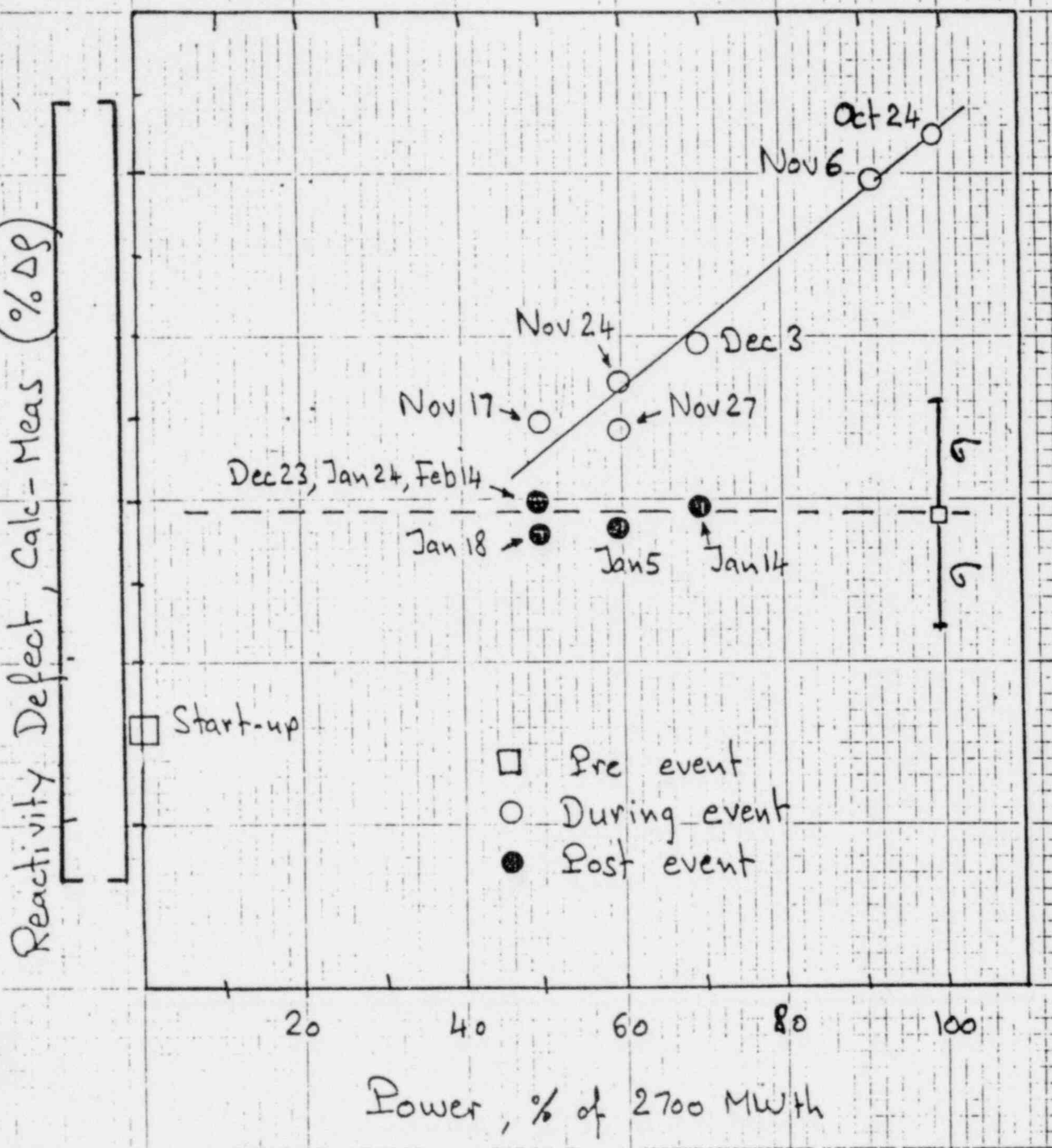


FIGURE III.2

Calvert-Cliffs I Cycle 4

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

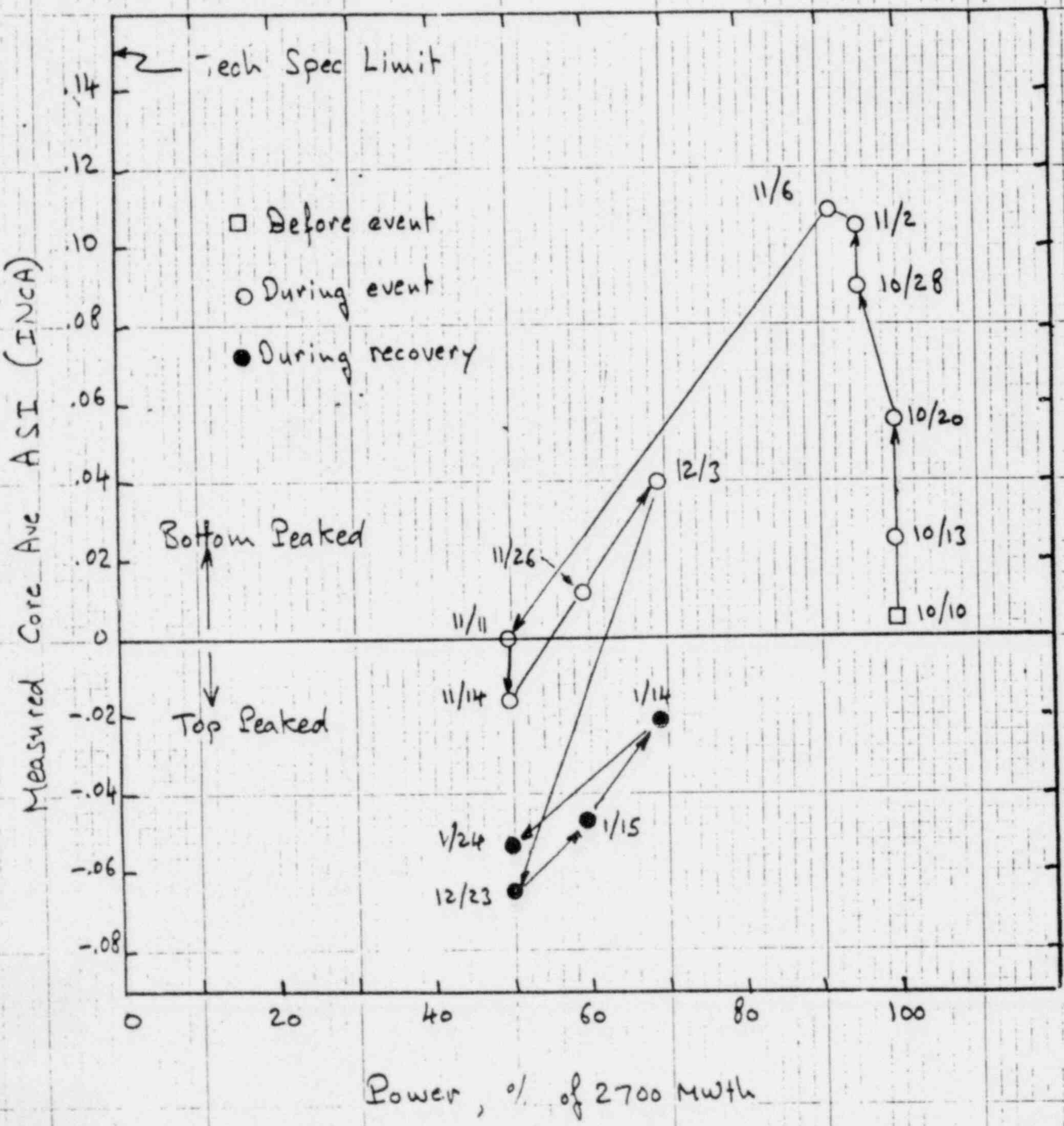


FIGURE III.3

Calvert Cliffs I Cycle 4

ASI Difference vs. Power Level

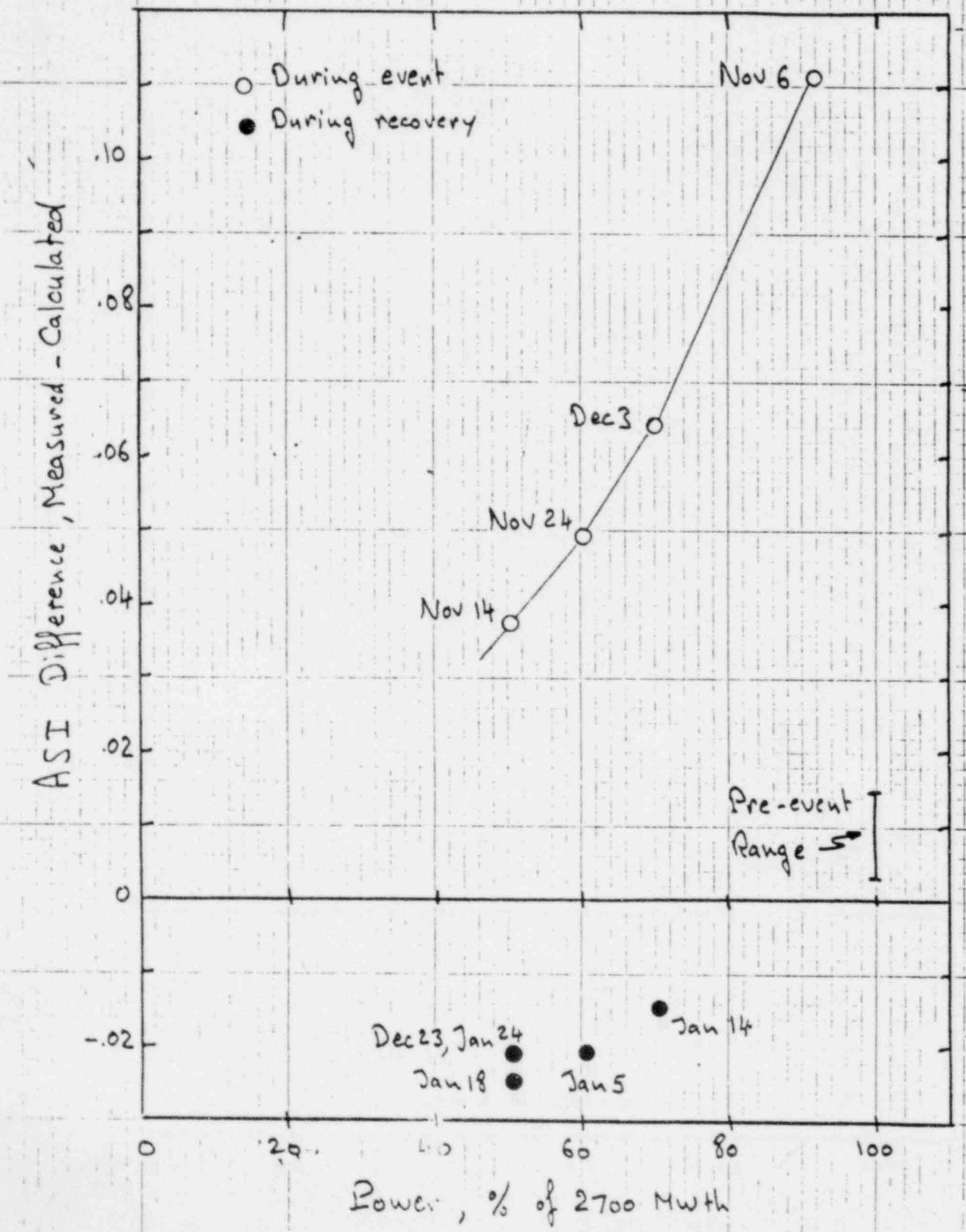


FIGURE III.4

Calvert Cliffs I Cycle 4

Measured Planar Peaking Factor F_{xy}

vs. Power and Time

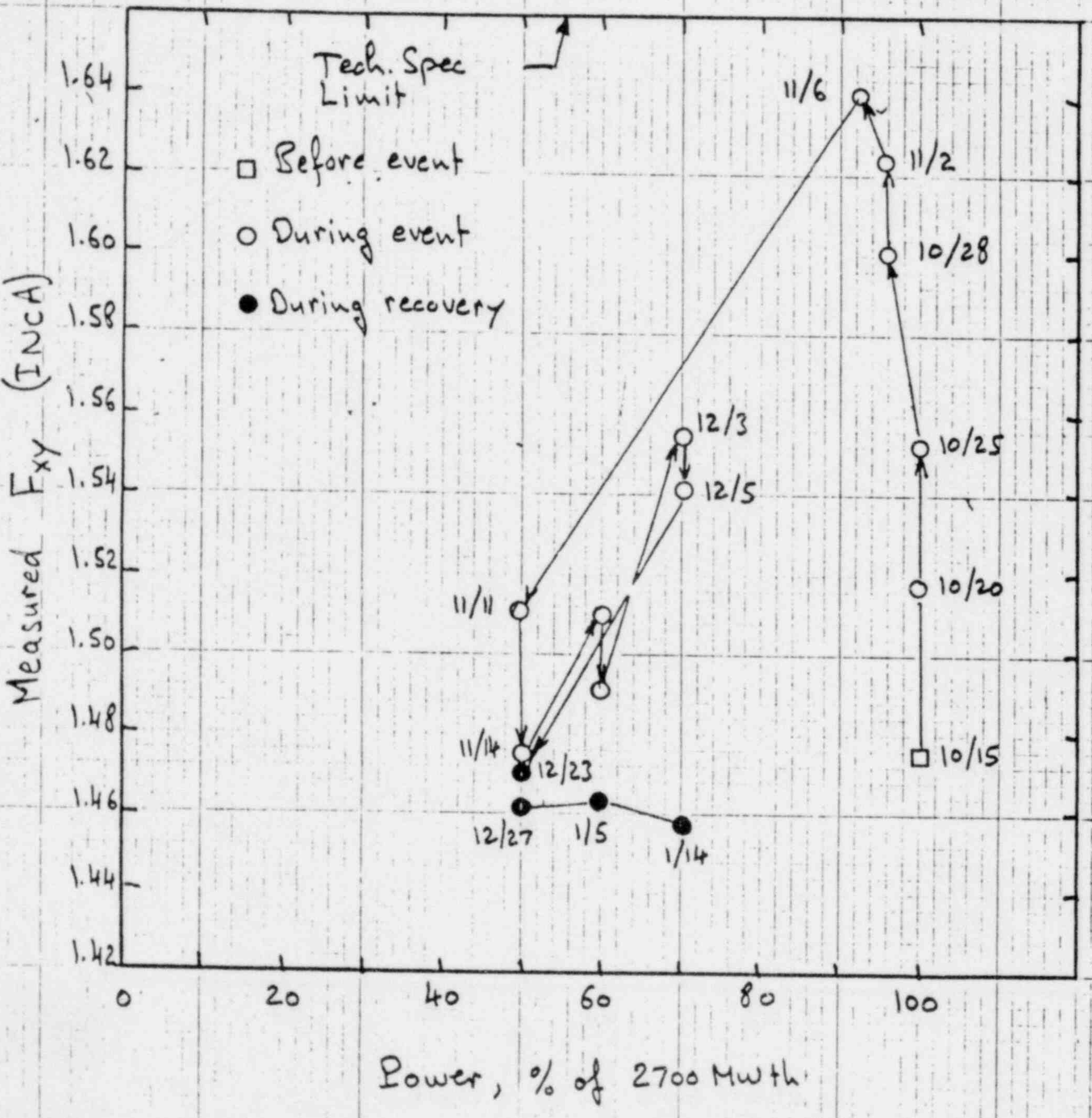


FIGURE III.5

Calvert - Cliffs I Cycle 4

Comparison of Measured and Predicted Radial Power Distributions at 80% Elevation

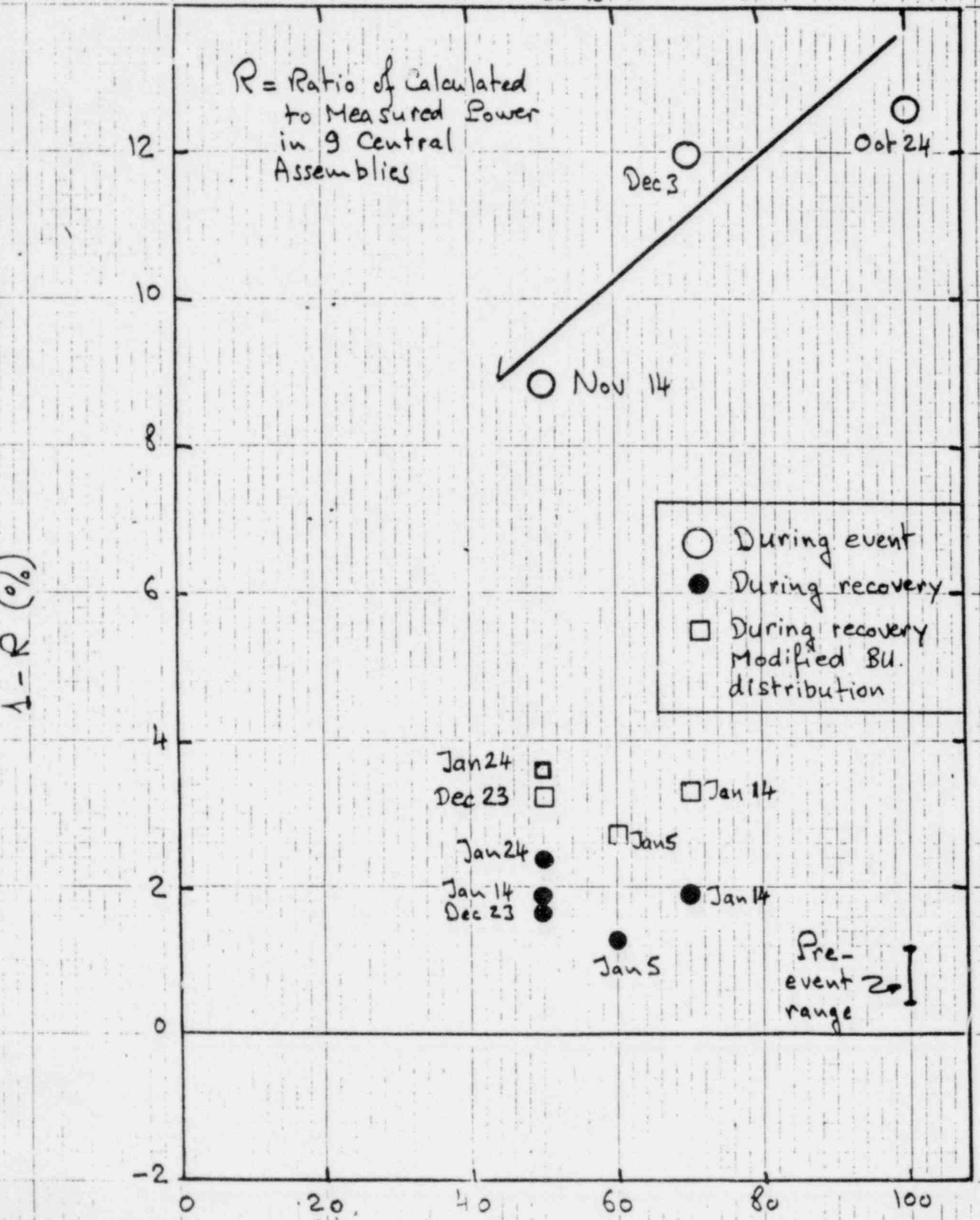
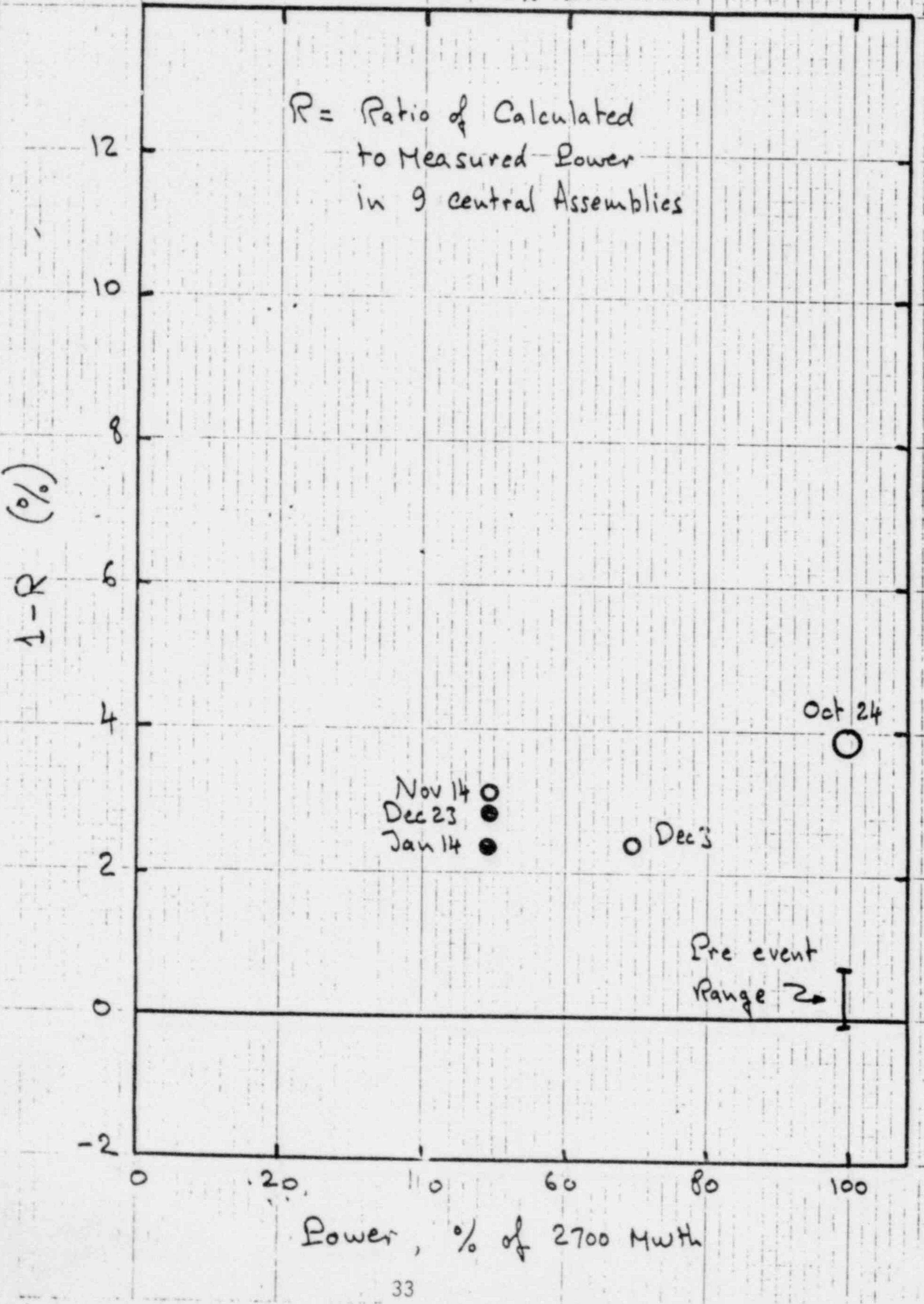


FIGURE III.6

Calvert Cliffs I Cycle 4

Comparison of Measured and Predicted Radial Power Distributions at 20% Elevation

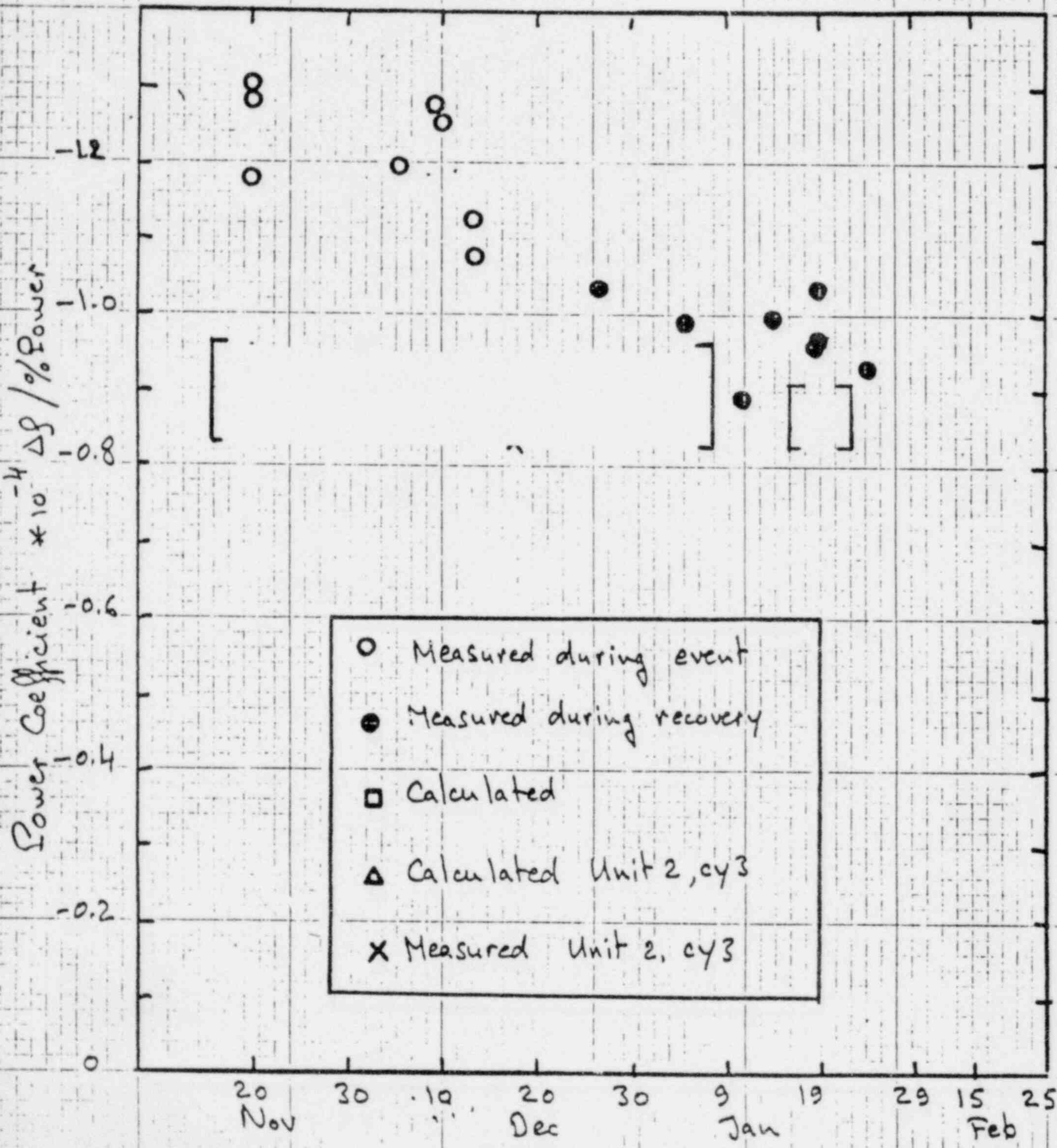


R = Ratio of Calculated to Measured Power in 9 central Assemblies

FIGURE III.7

Calvert Cliffs I Cycle 4

Power Coefficients* vs. Time



* Adjusted when necessary to 50% power

FIGURE III.8

Calvert Cliffs I Cycle 4

Calculated - Measured Power Coefficient

vs. Time

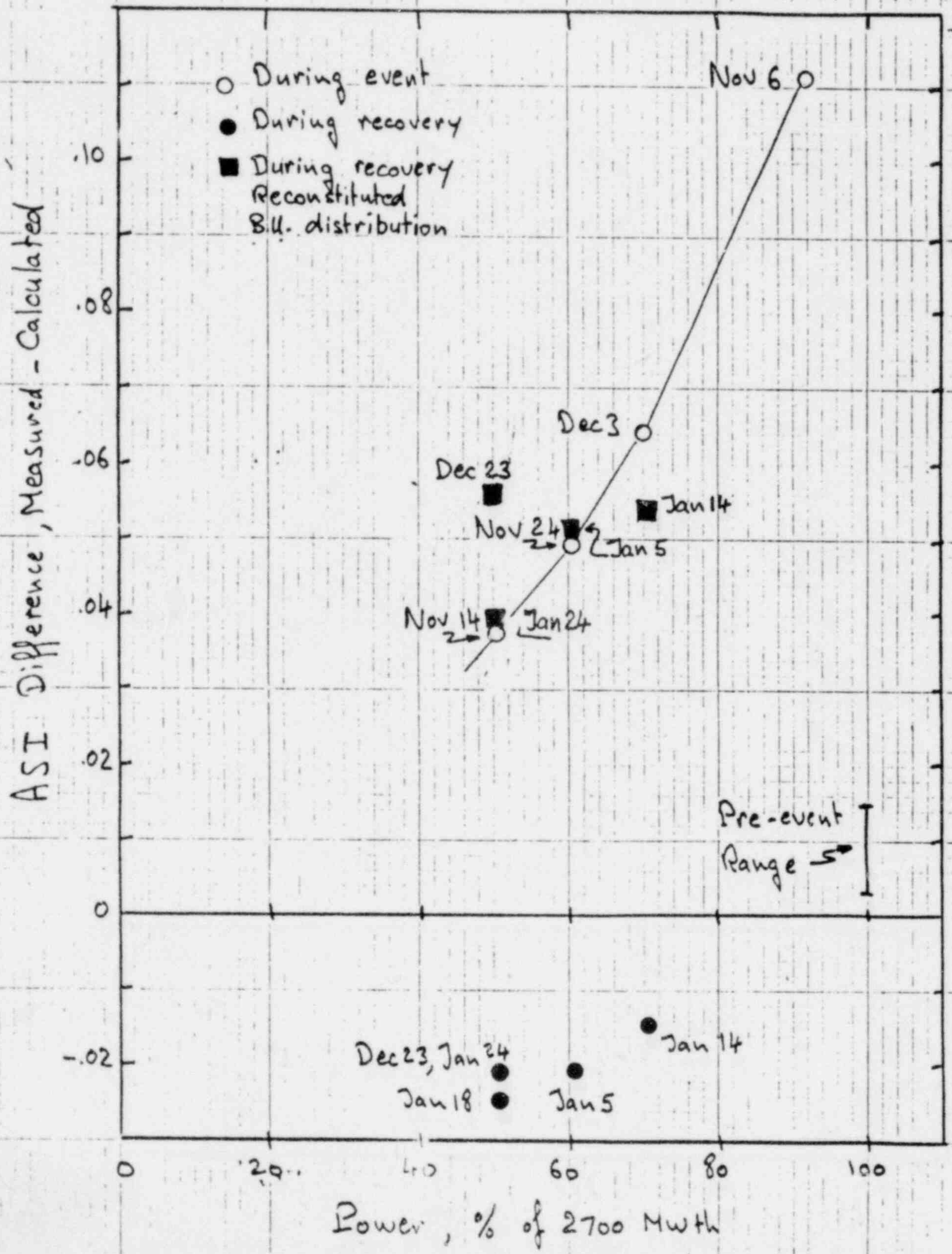
Power Coef. Difference, Calc - Meas ($*10^{-4}$/%P)

Time

FIGURE III.9

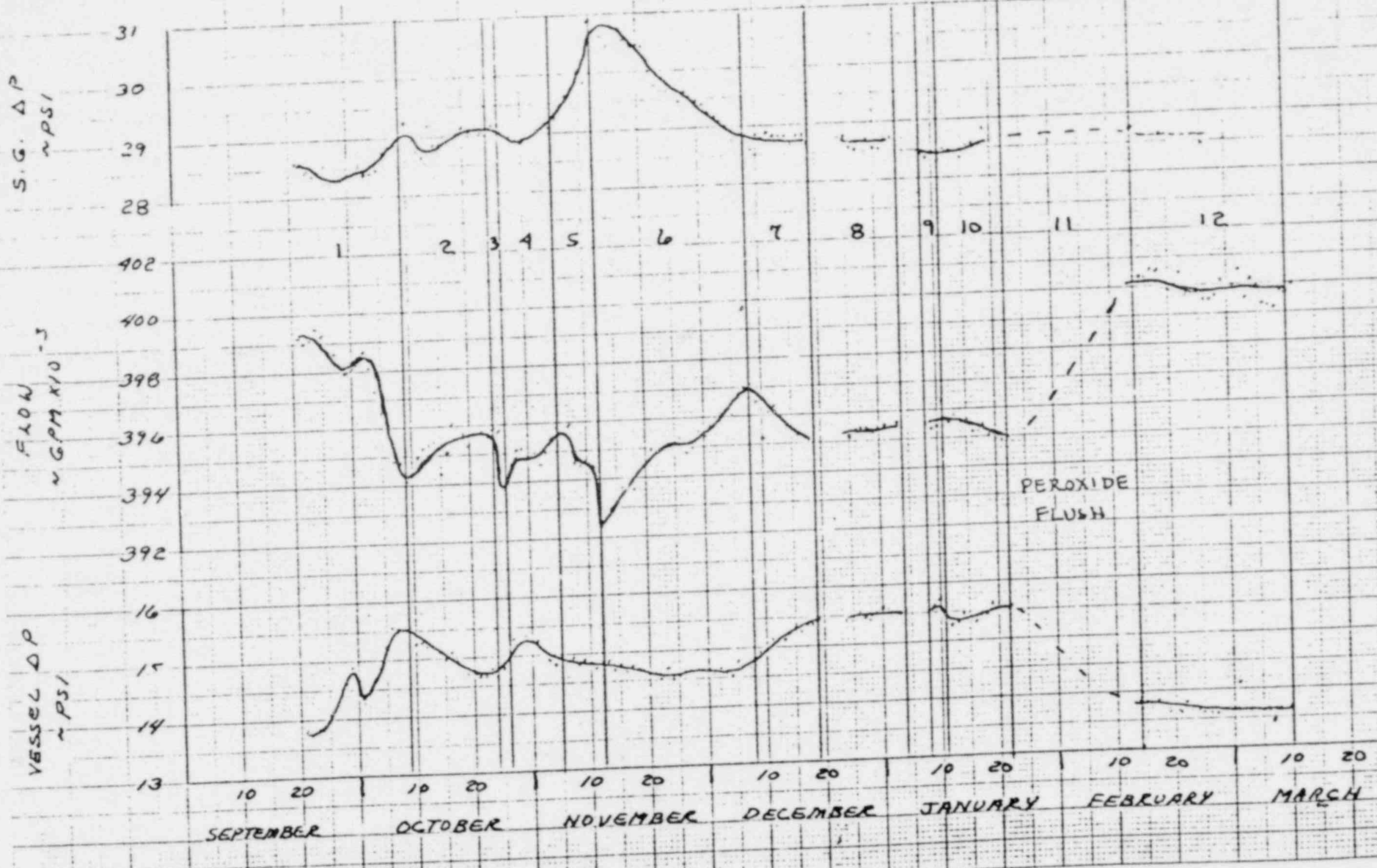
Calvert Cliffs I Cycle 4

ASI Difference vs. Power Level



461510

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



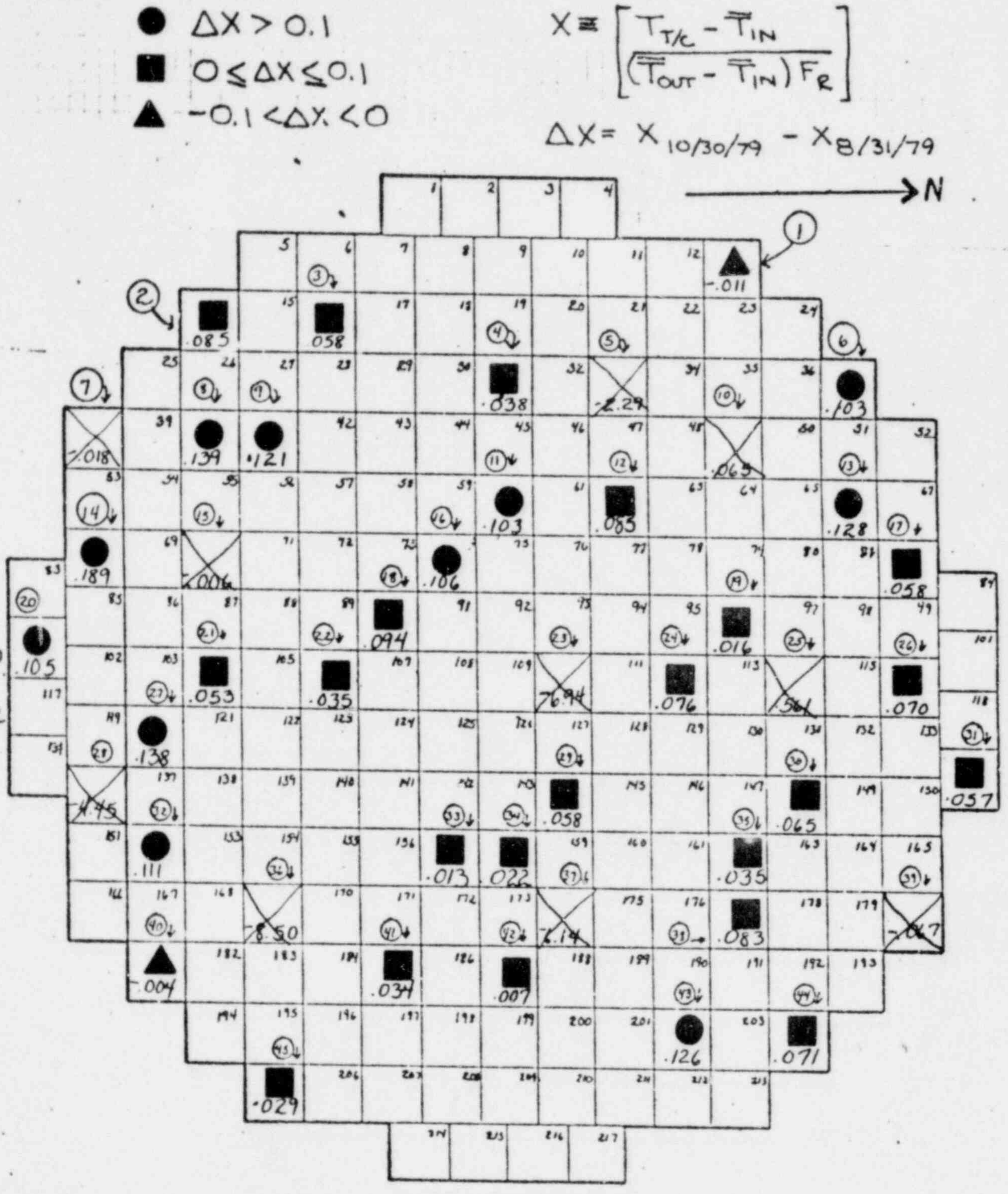


FIGURE III.11

THERMOCOUPLE READINGS COMPARED PRE-ANOMALY TO MID-ANOMALY

● $\Delta X > 0.1$

■ $0 \leq \Delta X \leq 0.1$

▲ $-0.1 < \Delta X < 0$

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

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

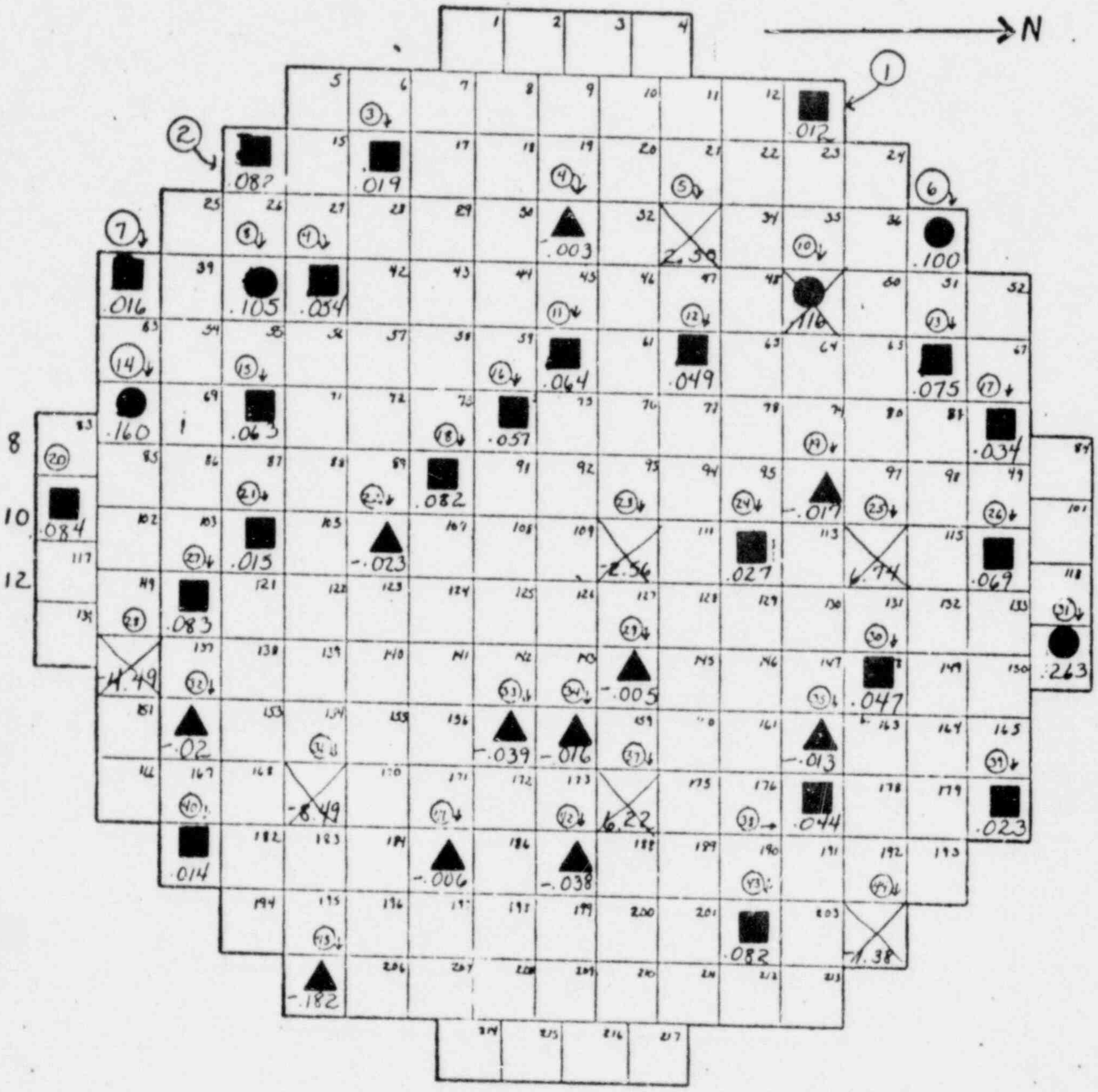


FIGURE III.12

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 (μmho/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

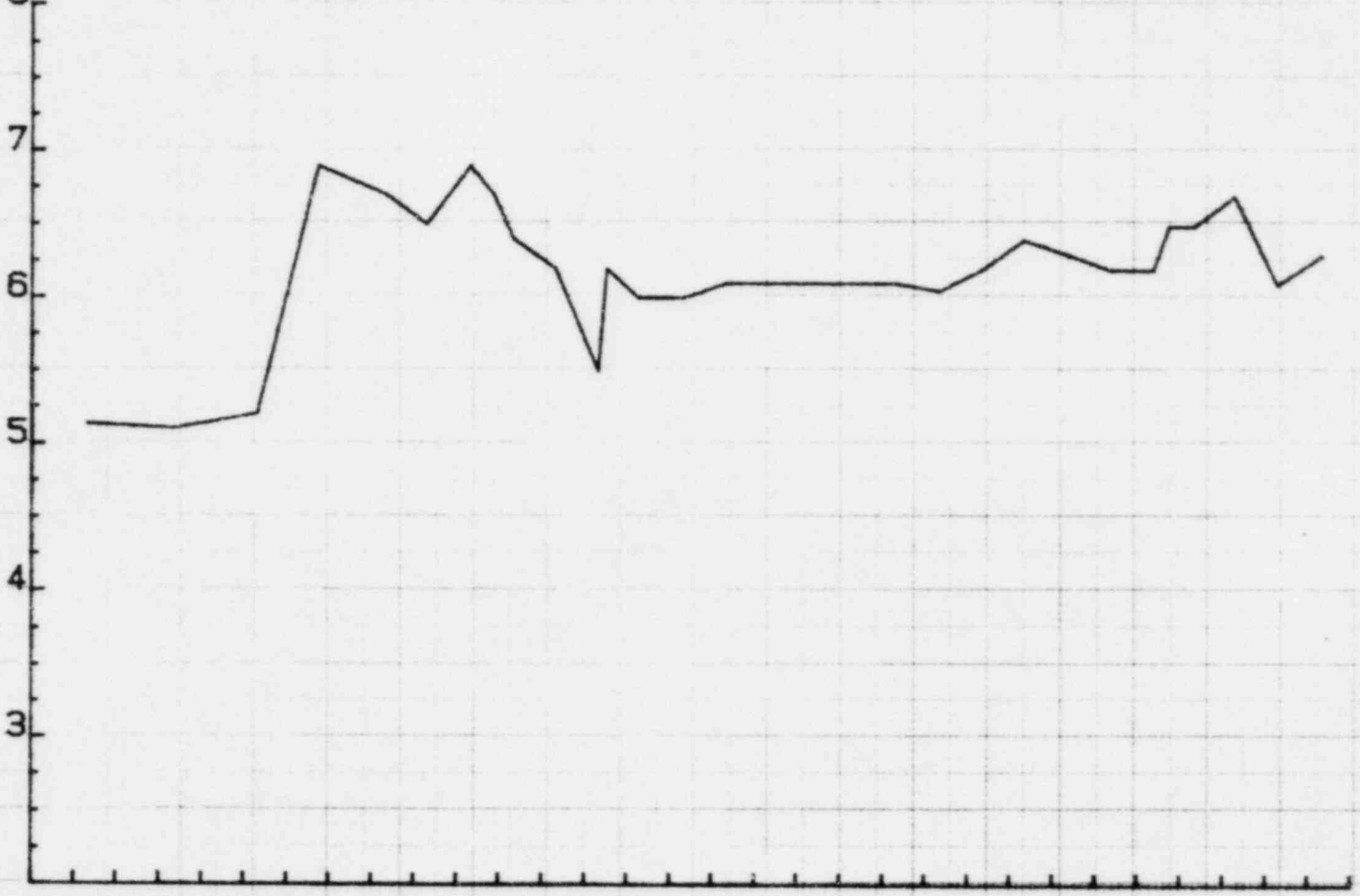
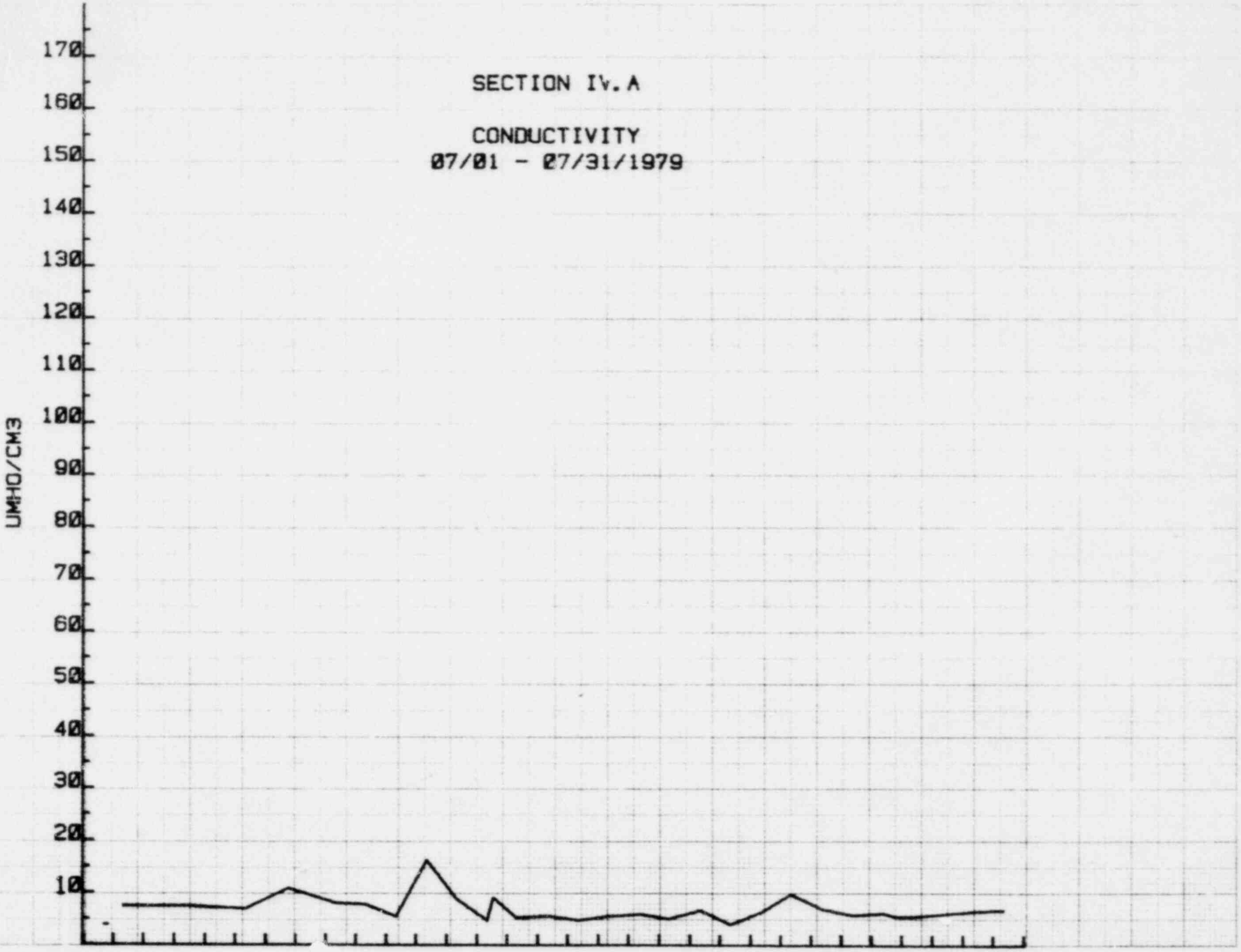


FIGURE 1B

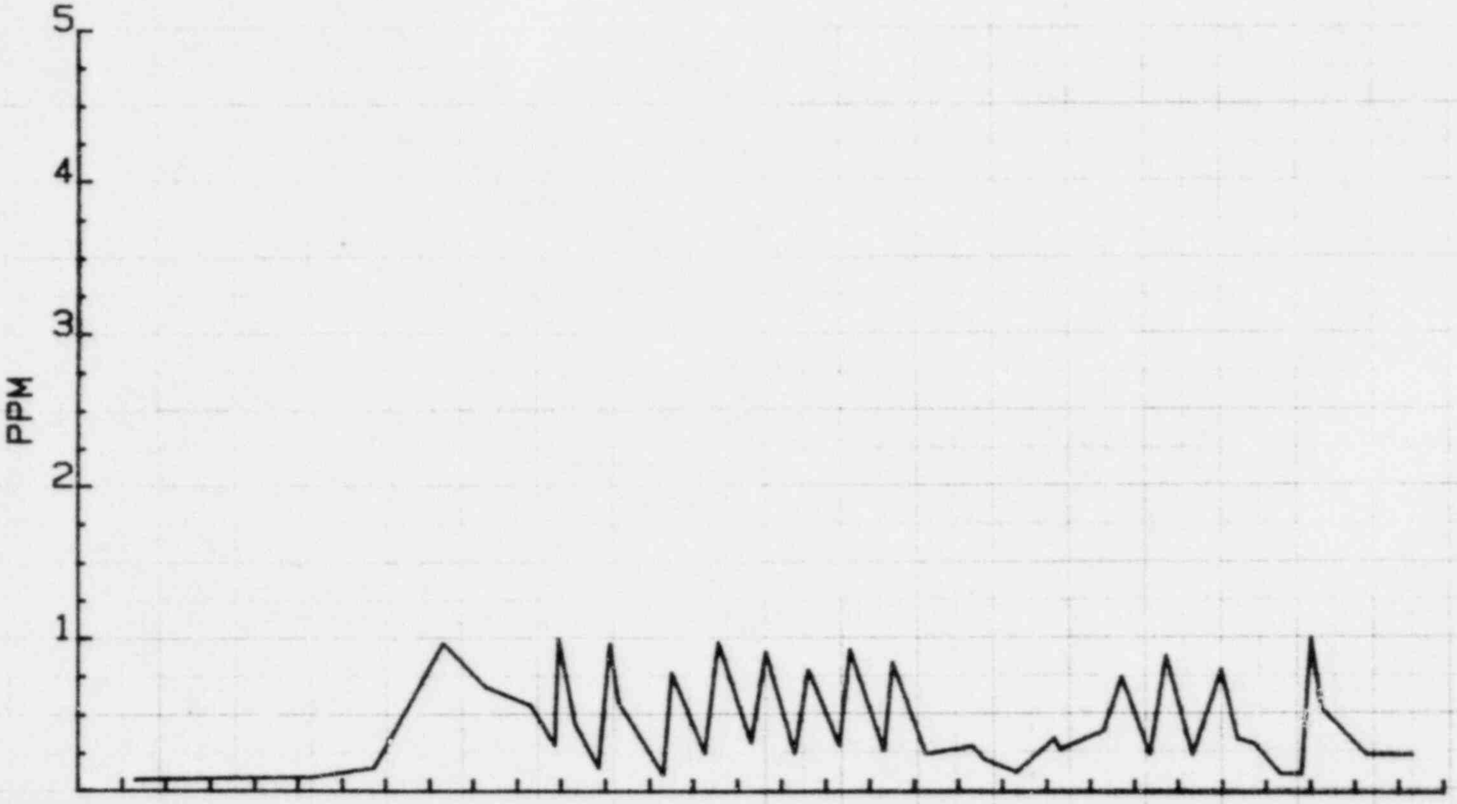

SECTION IV.A

CONDUCTIVITY
07/01 - 07/31/1979

FIGURE 1C

SECTION IV. A

LITHIUM
07/01 - 07-31/1979



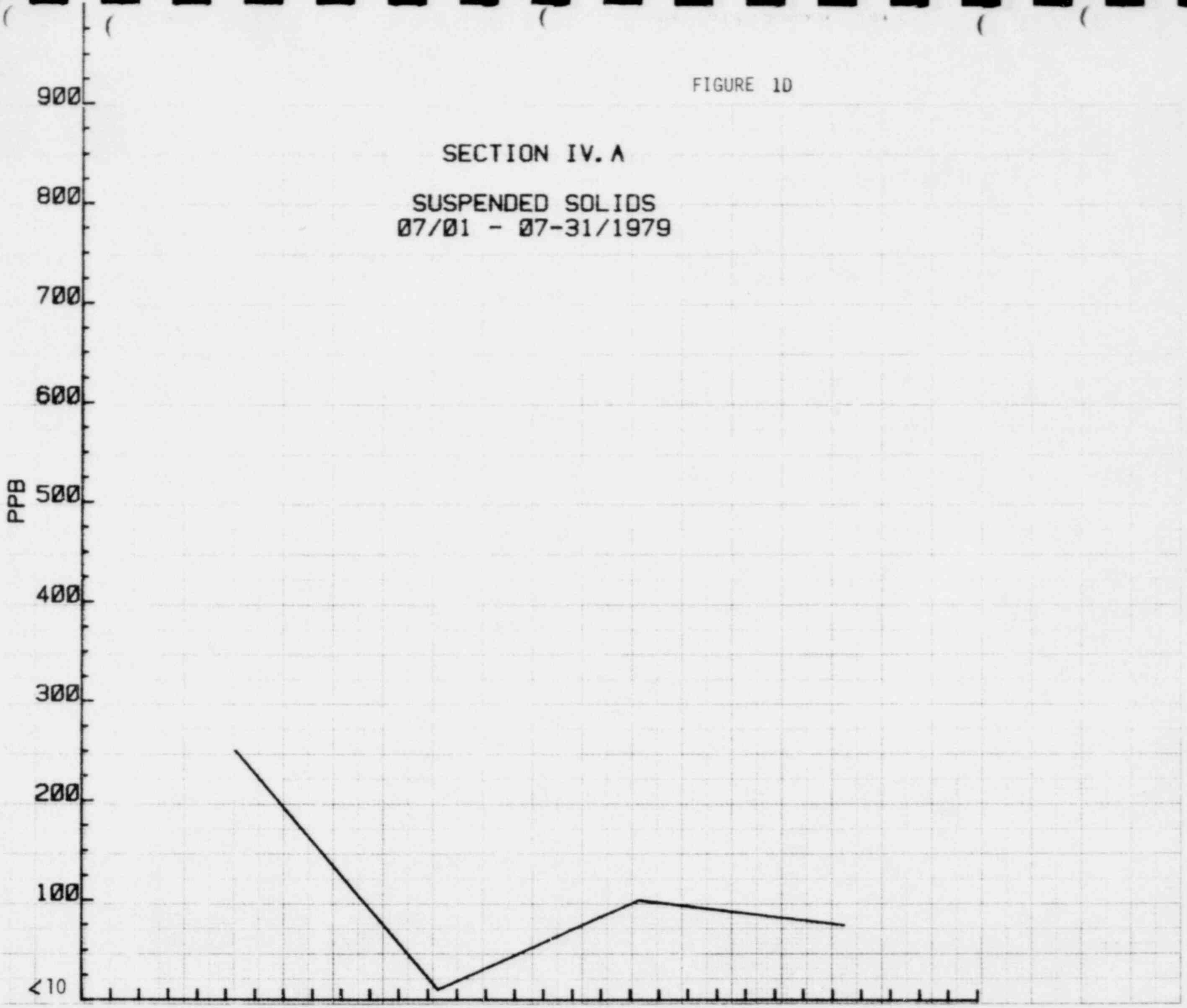


FIGURE 1D

SECTION IV.A

SUSPENDED SOLIDS
07/01 - 07-31/1979

FIGURE 1E

SECTION IV.A

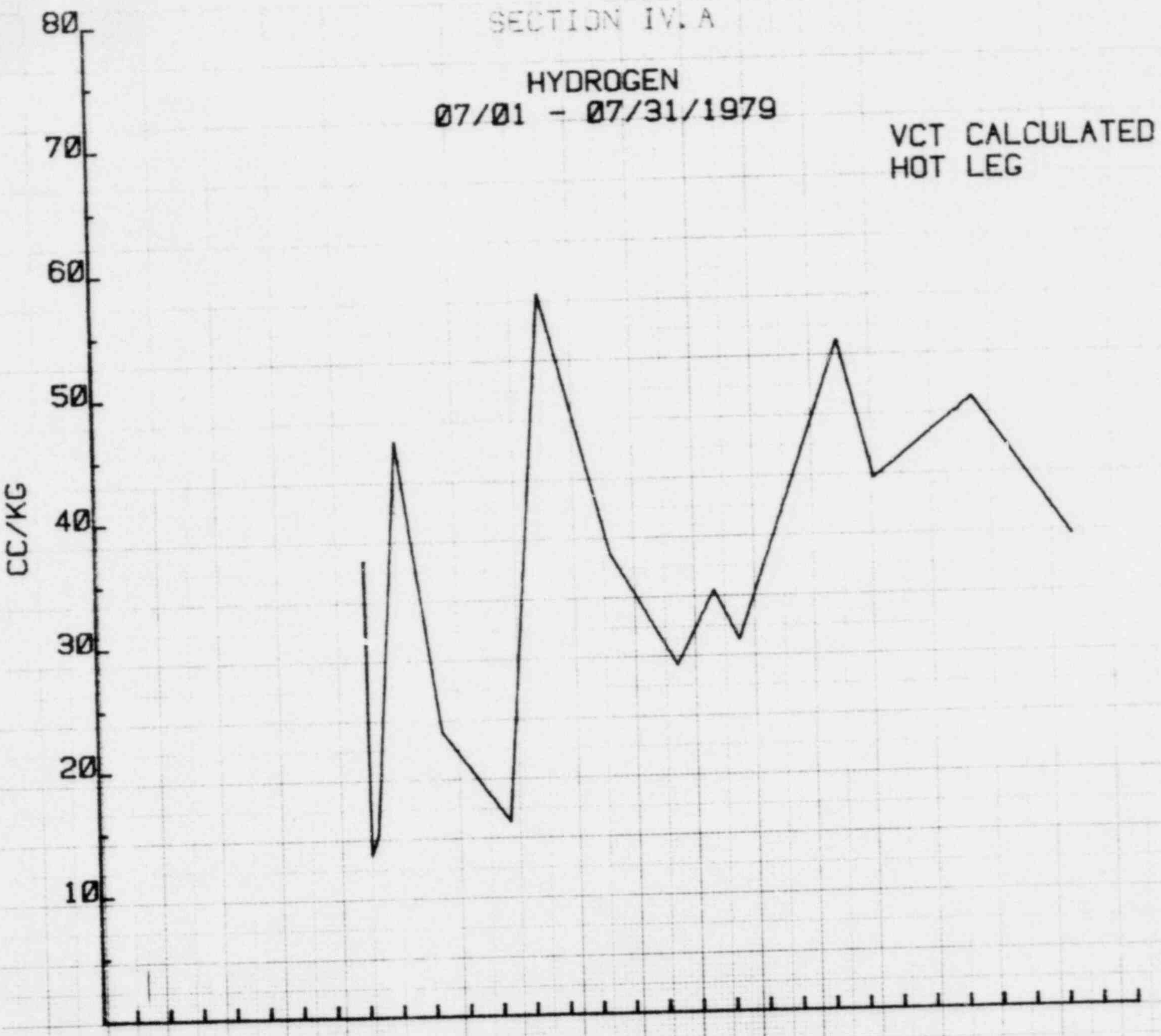
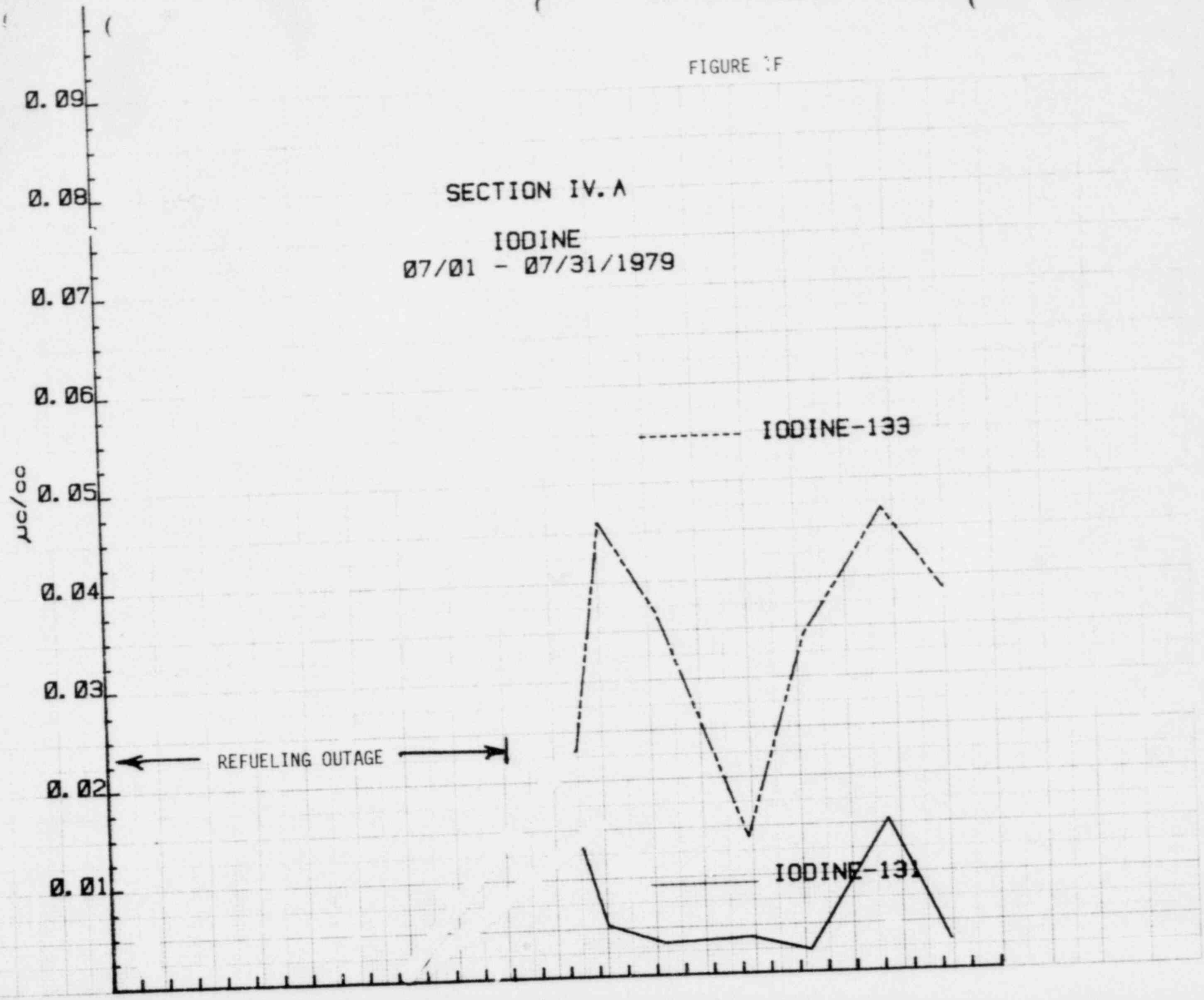


FIGURE 1F



SECTION IV.A

IODINE
07/01 - 07/31/1979

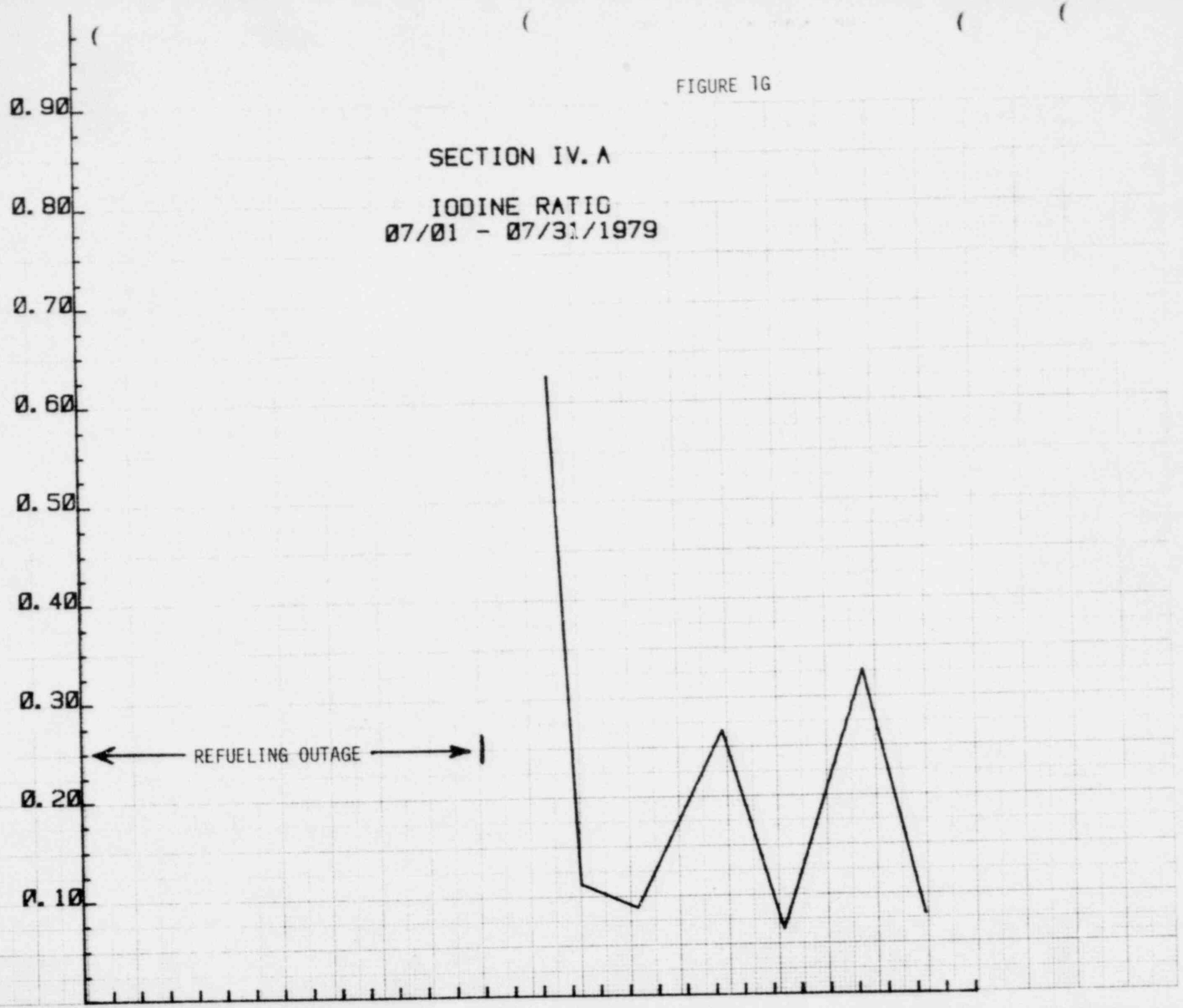
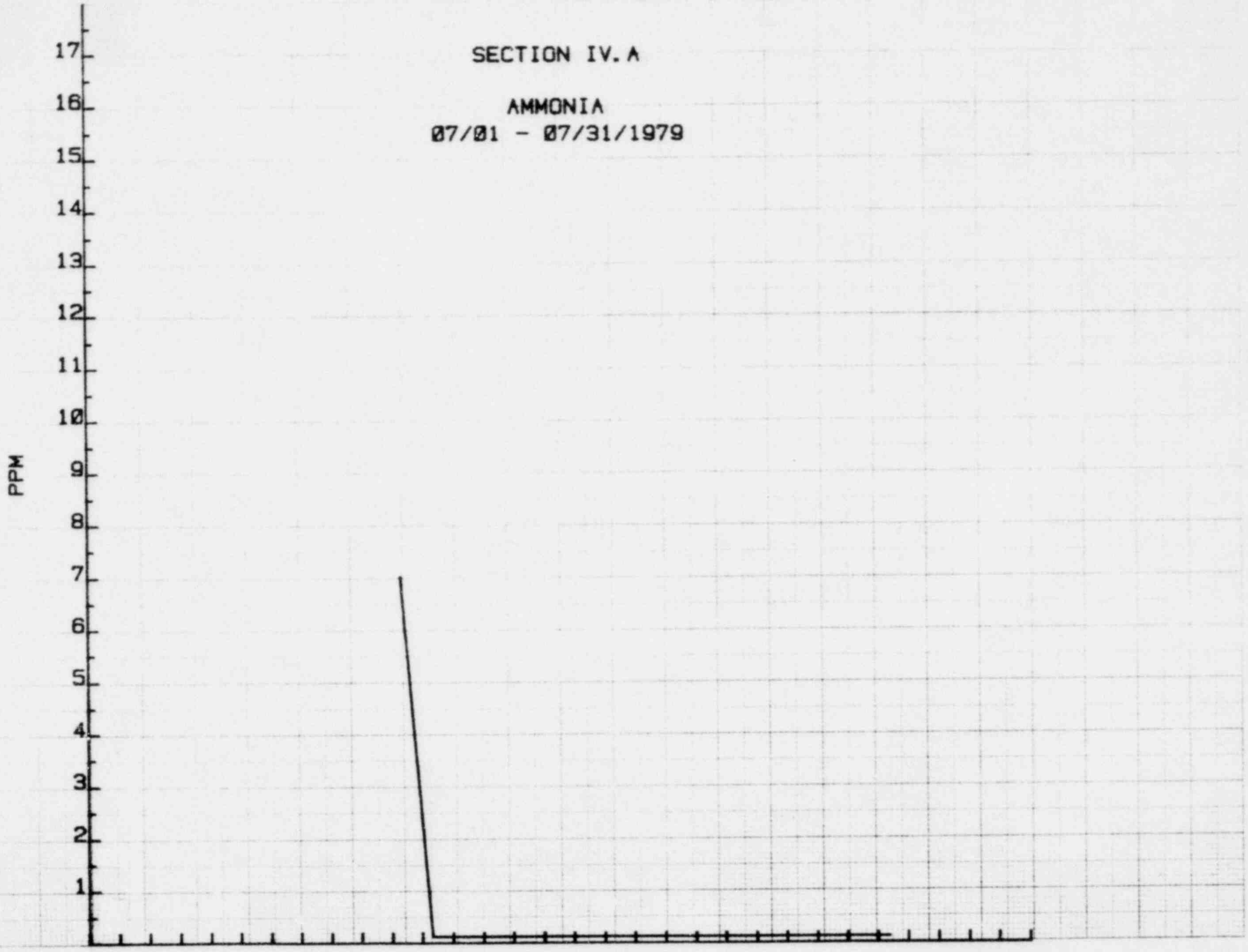


FIGURE 1G

SECTION IV. A

IODINE RATIO
07/01 - 07/31/1979

FIGURE 1H


SECTION IV. A
AMMONIA
07/01 - 07/31/1979
PPM
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1

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 Attachement 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 (μmhos/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

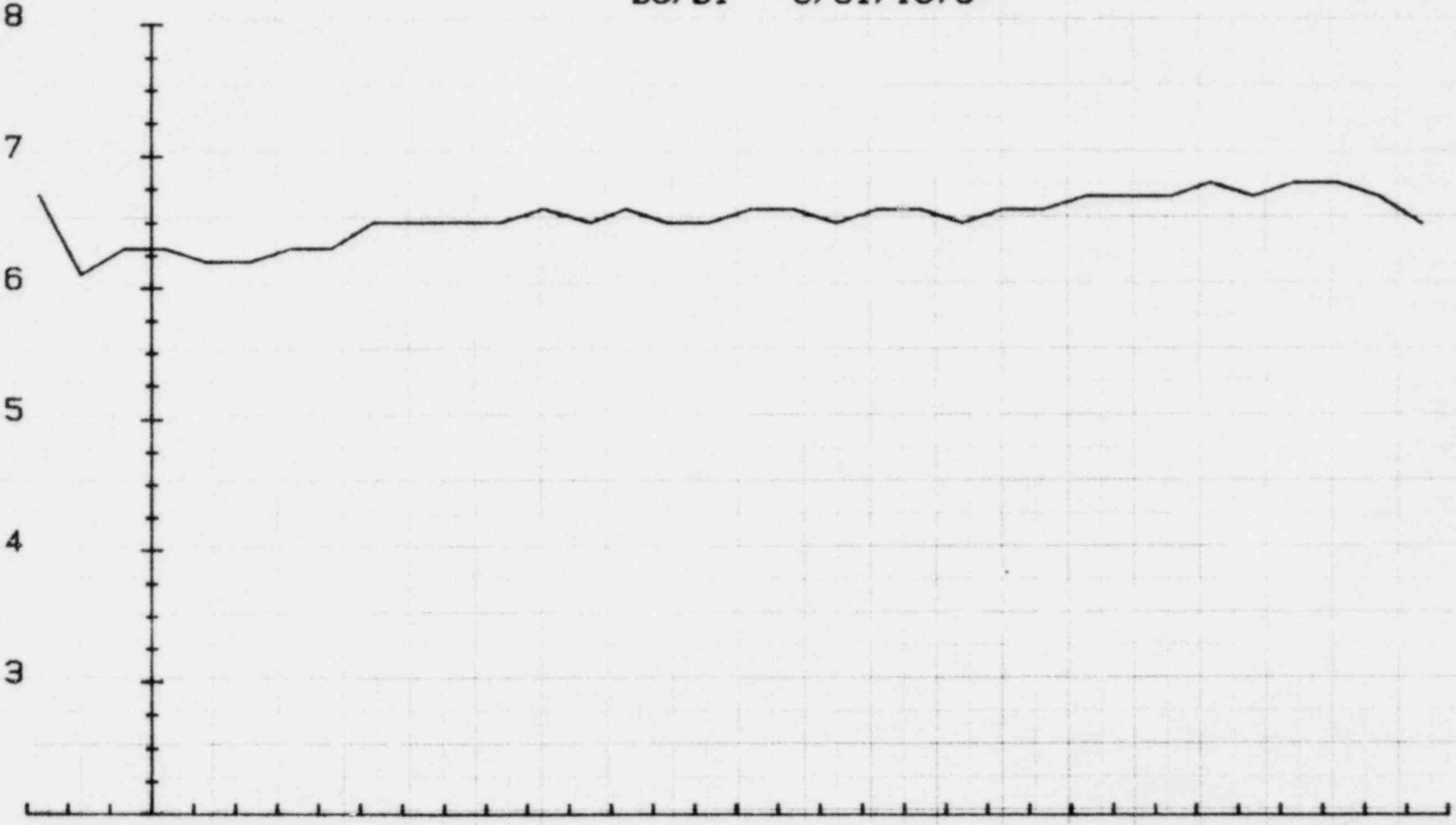


FIGURE B.2

SECTION IV.B

PH @ 25°C
09/01 - 09/30/1979

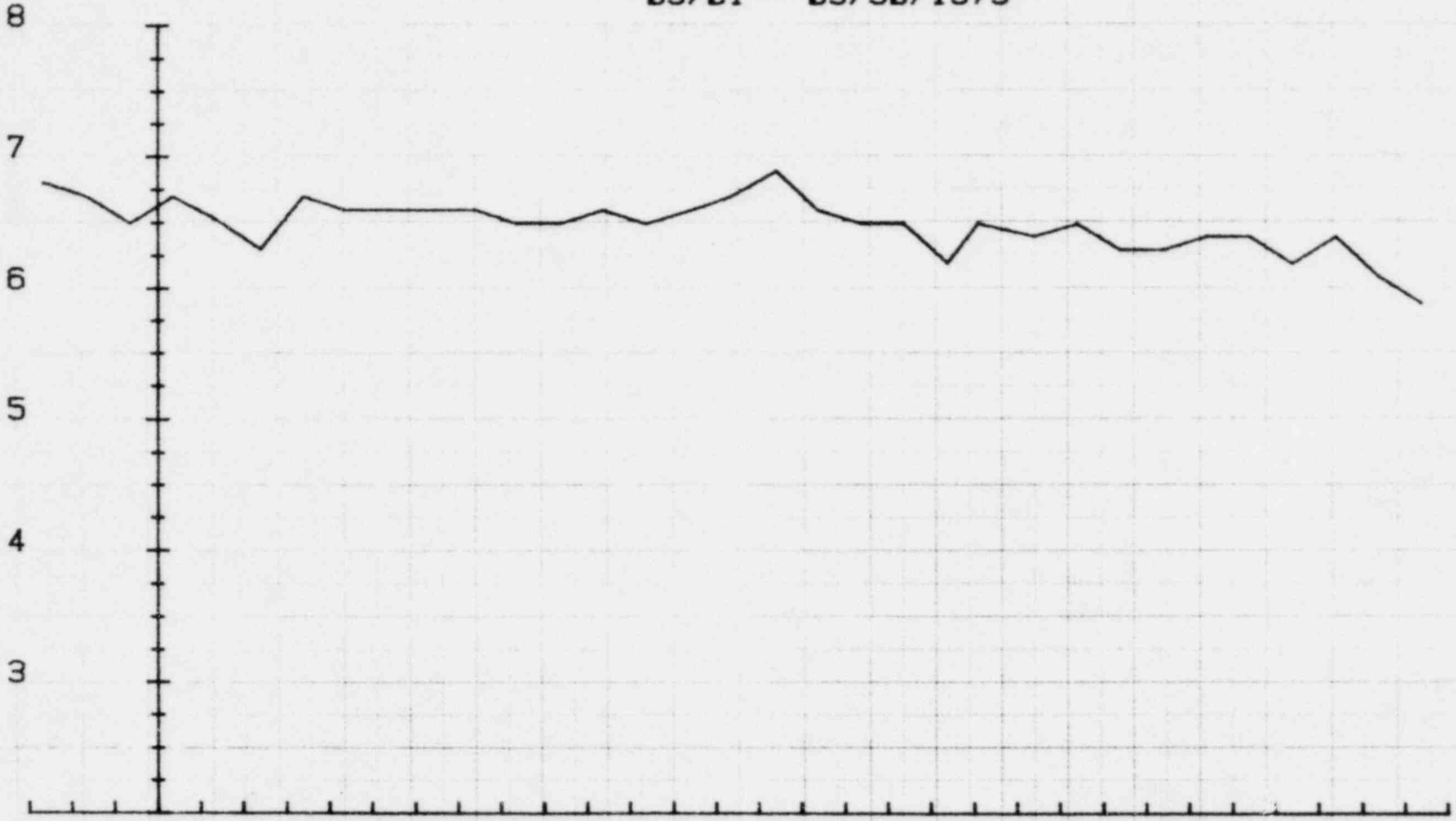


FIGURE B.3

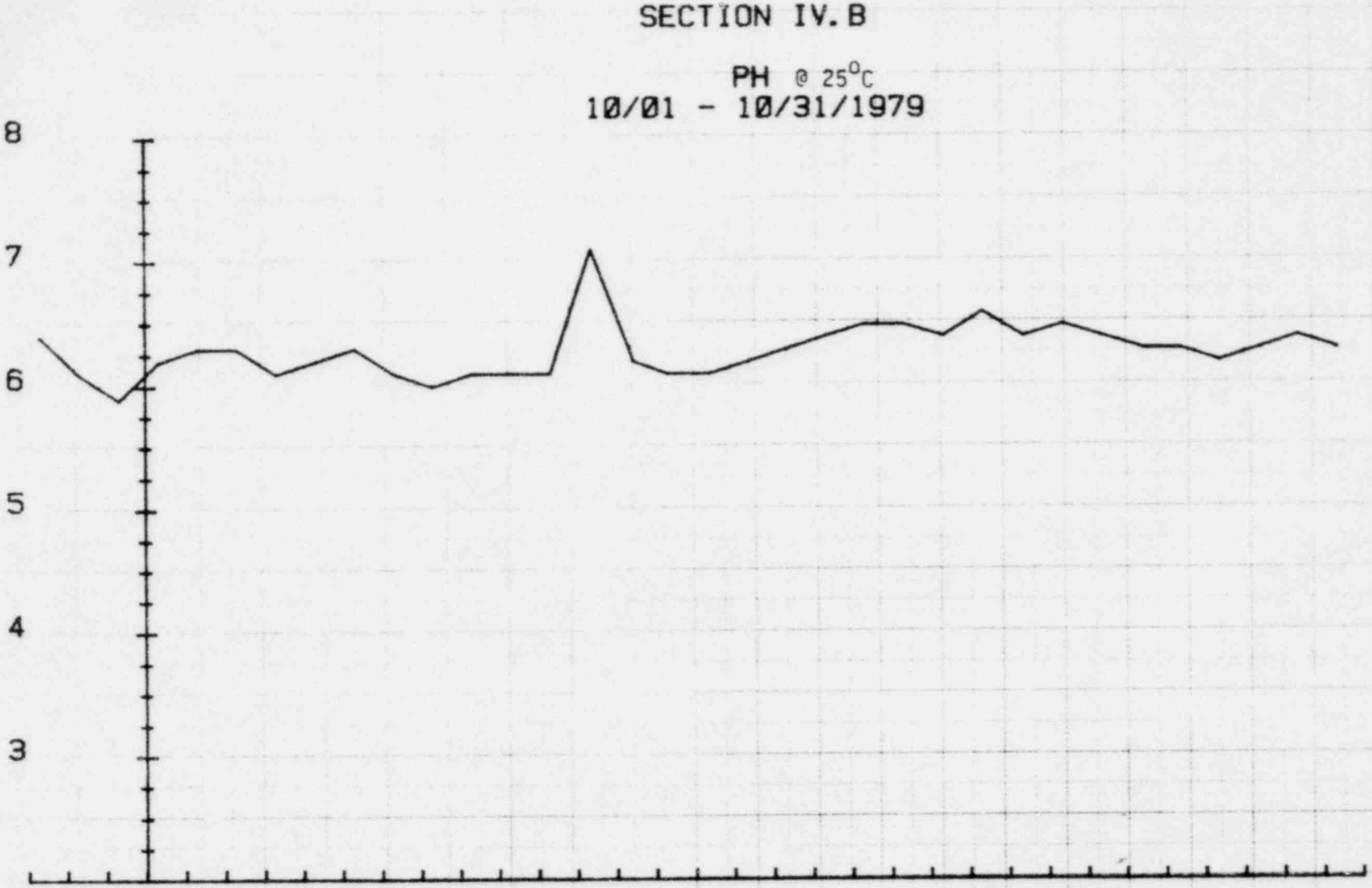


FIGURE B.4

SECTION IV.B

PH @ 25°C
11/01 - 11/30/1979

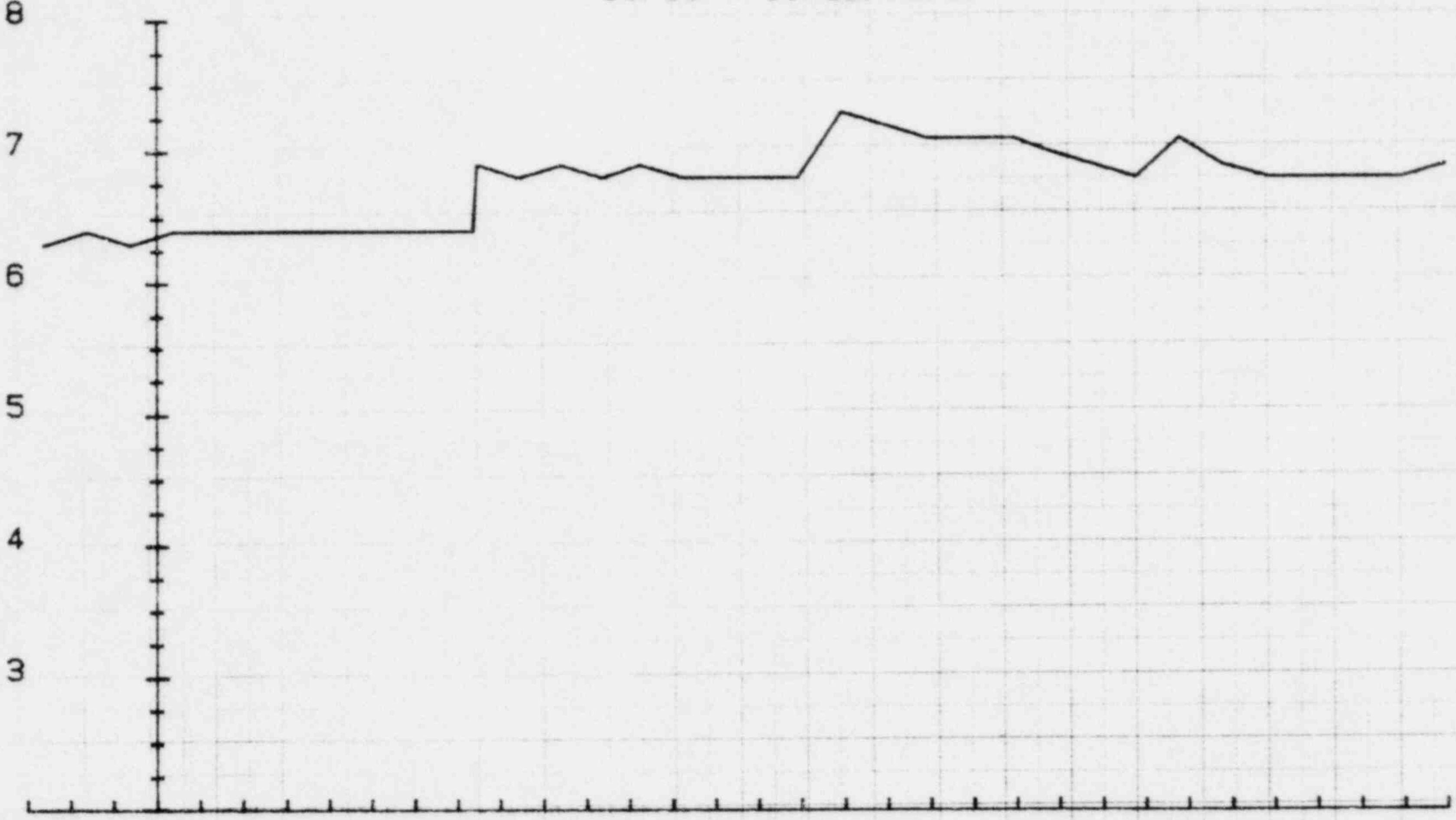


FIGURE B.5

SECTION IV.B

PH @ 25°C
12/01 - 12/31/1979

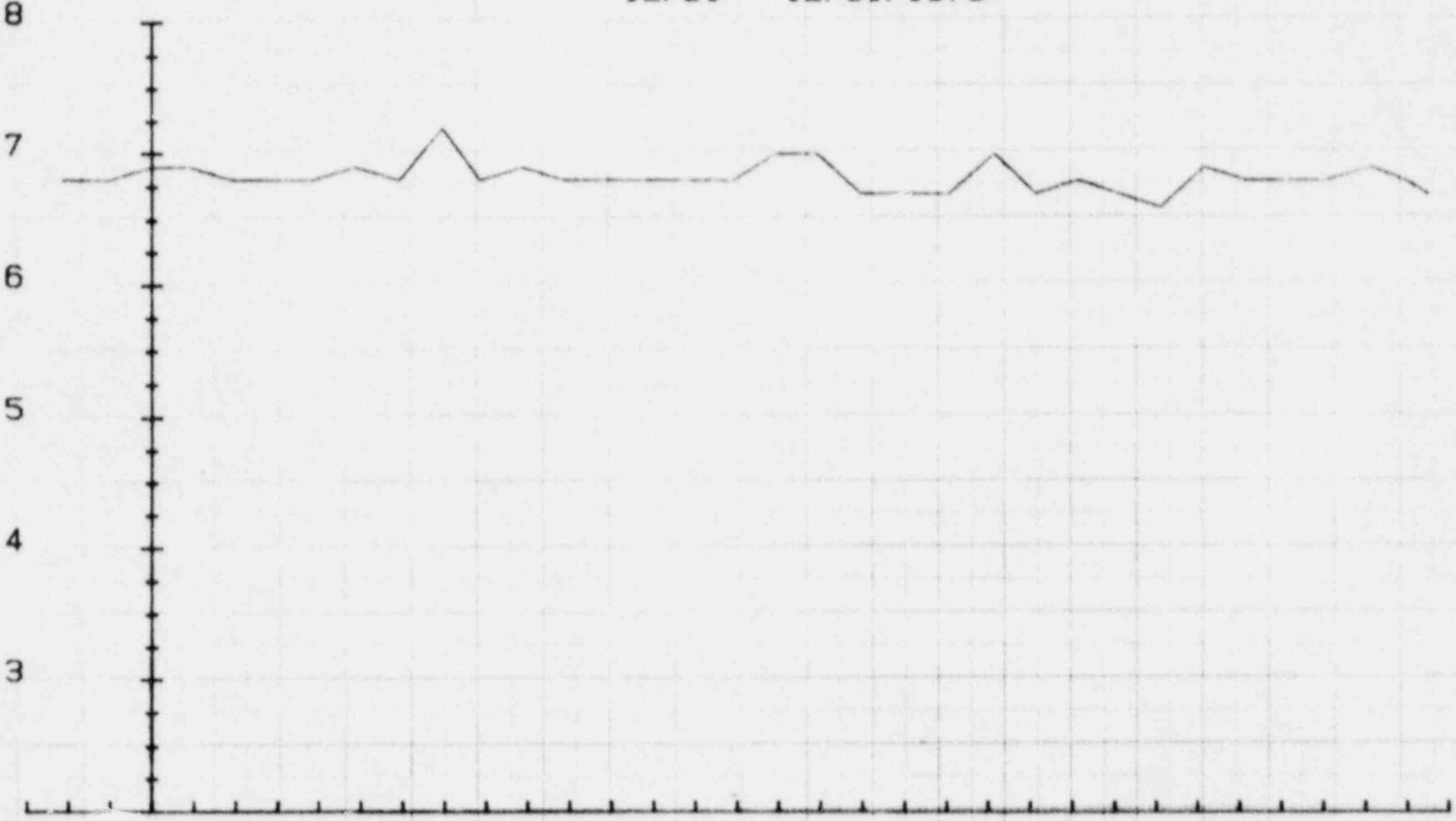
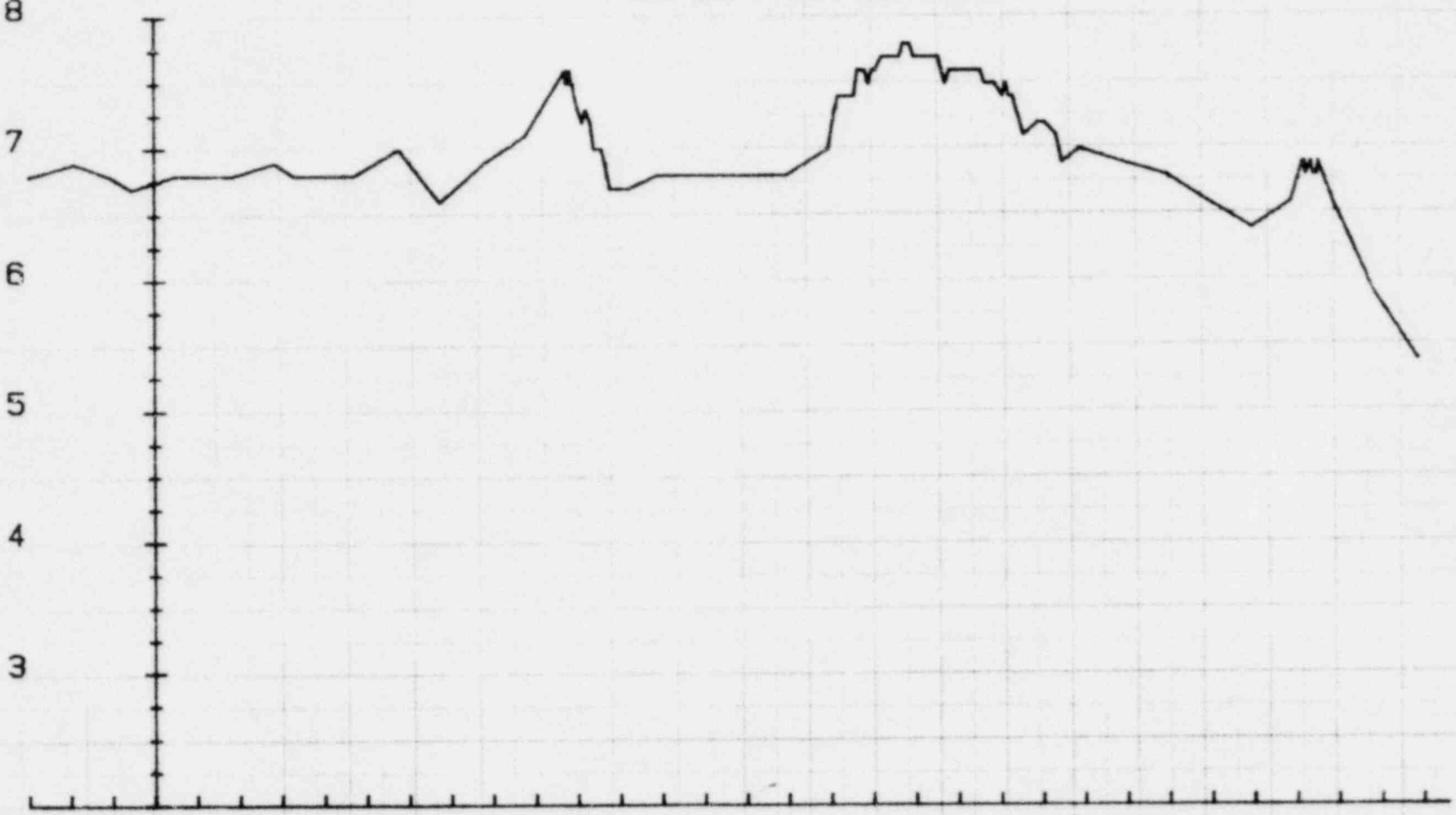


FIGURE B.6



SECTION IV.B

PH @ 25°C
01/01 - 01/31/1980

FIGURE B.7

SECTION IV.B

PH @ 25°C
02/01 - 02/29/1980

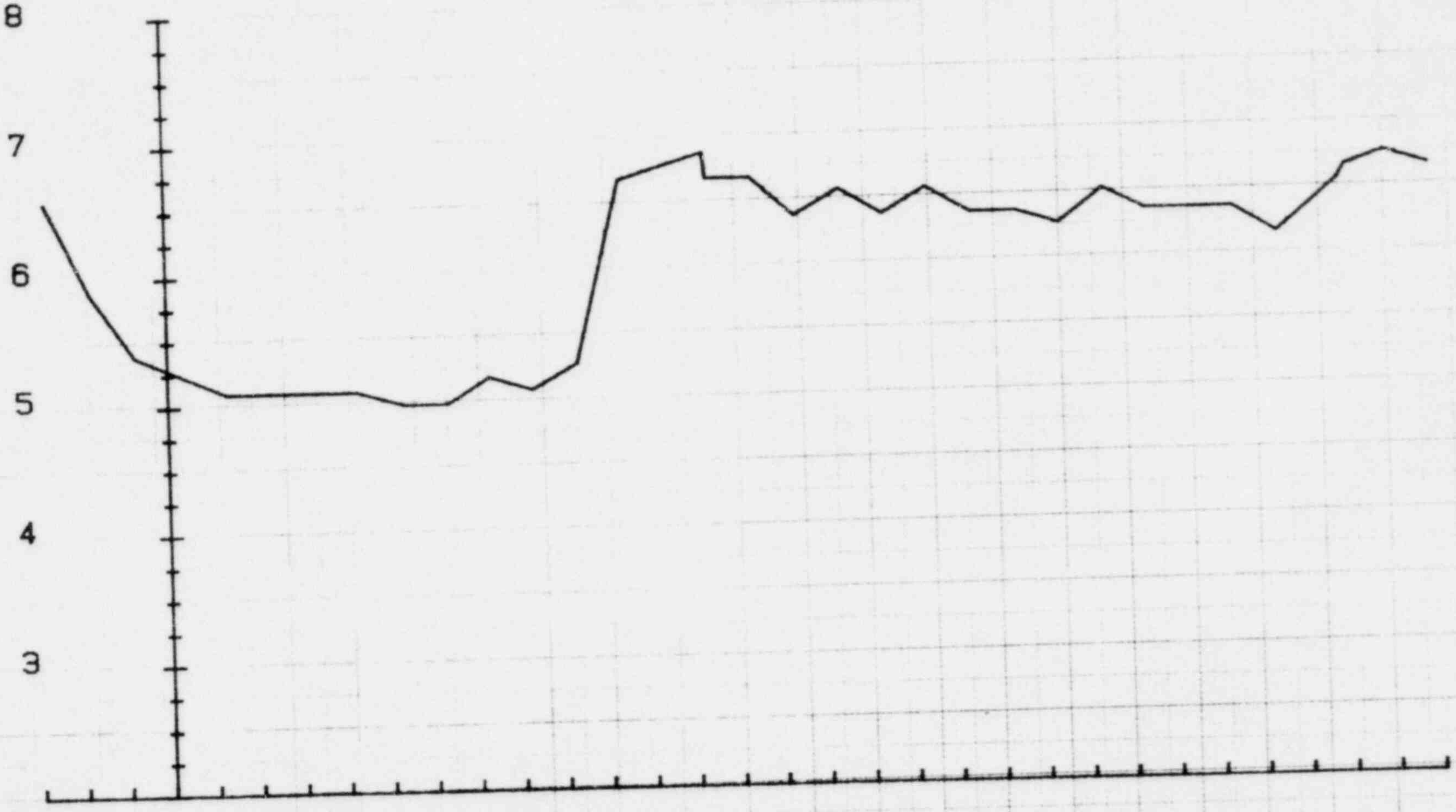
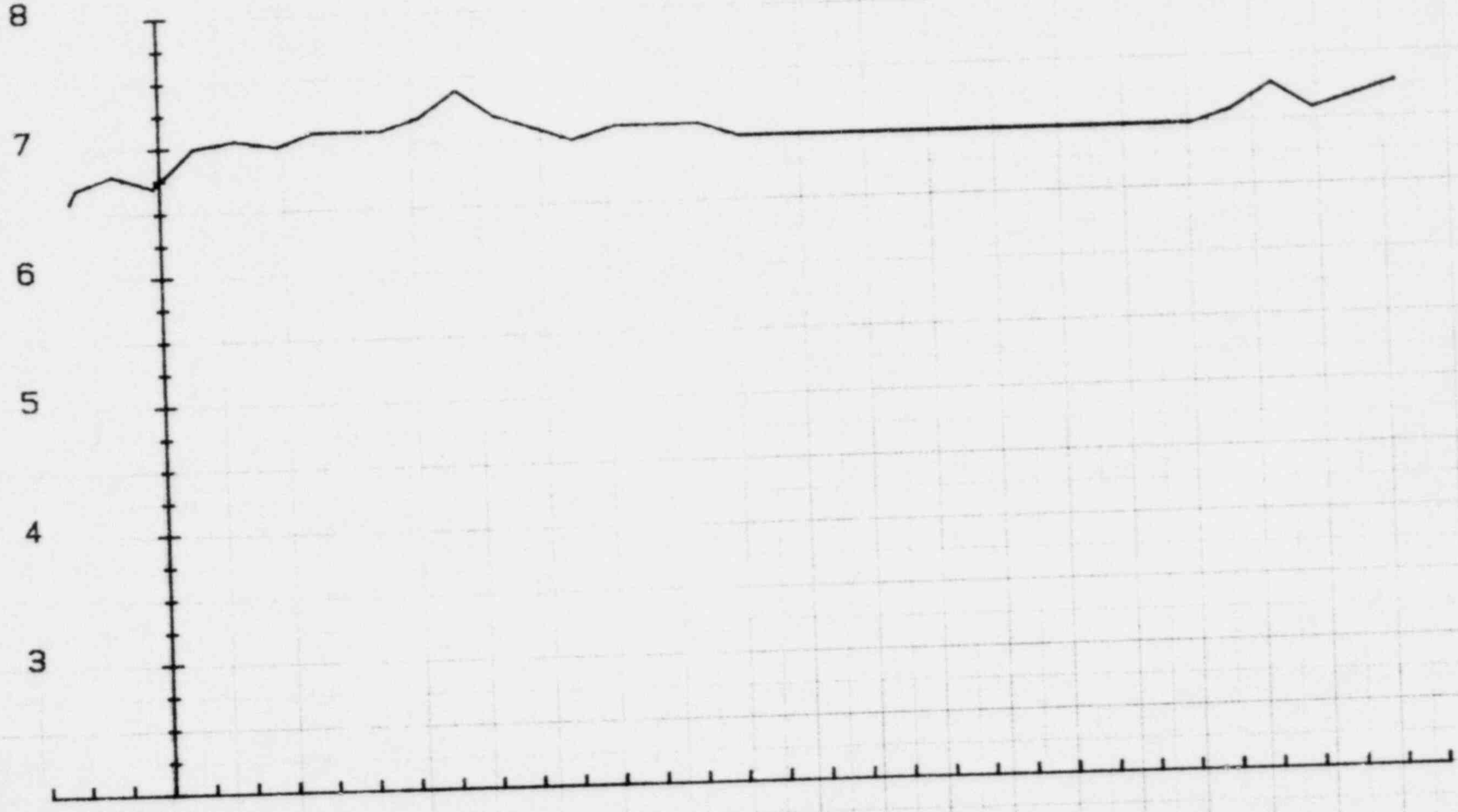


FIGURE B.8

SECTION IV.B

PH @ 25°C
03/01 - 03/31/1980



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 condictivity 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 10-20μmhos/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

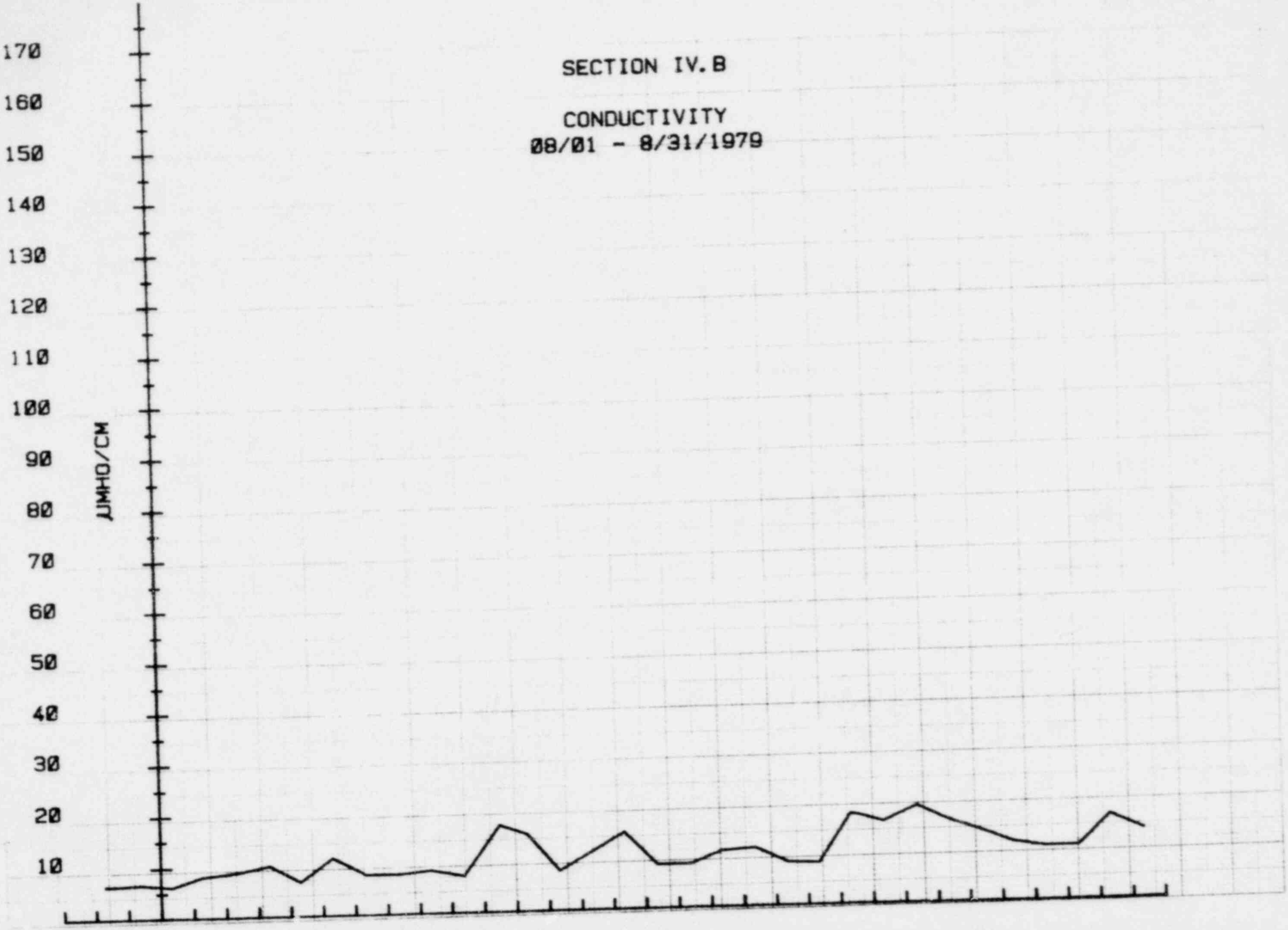
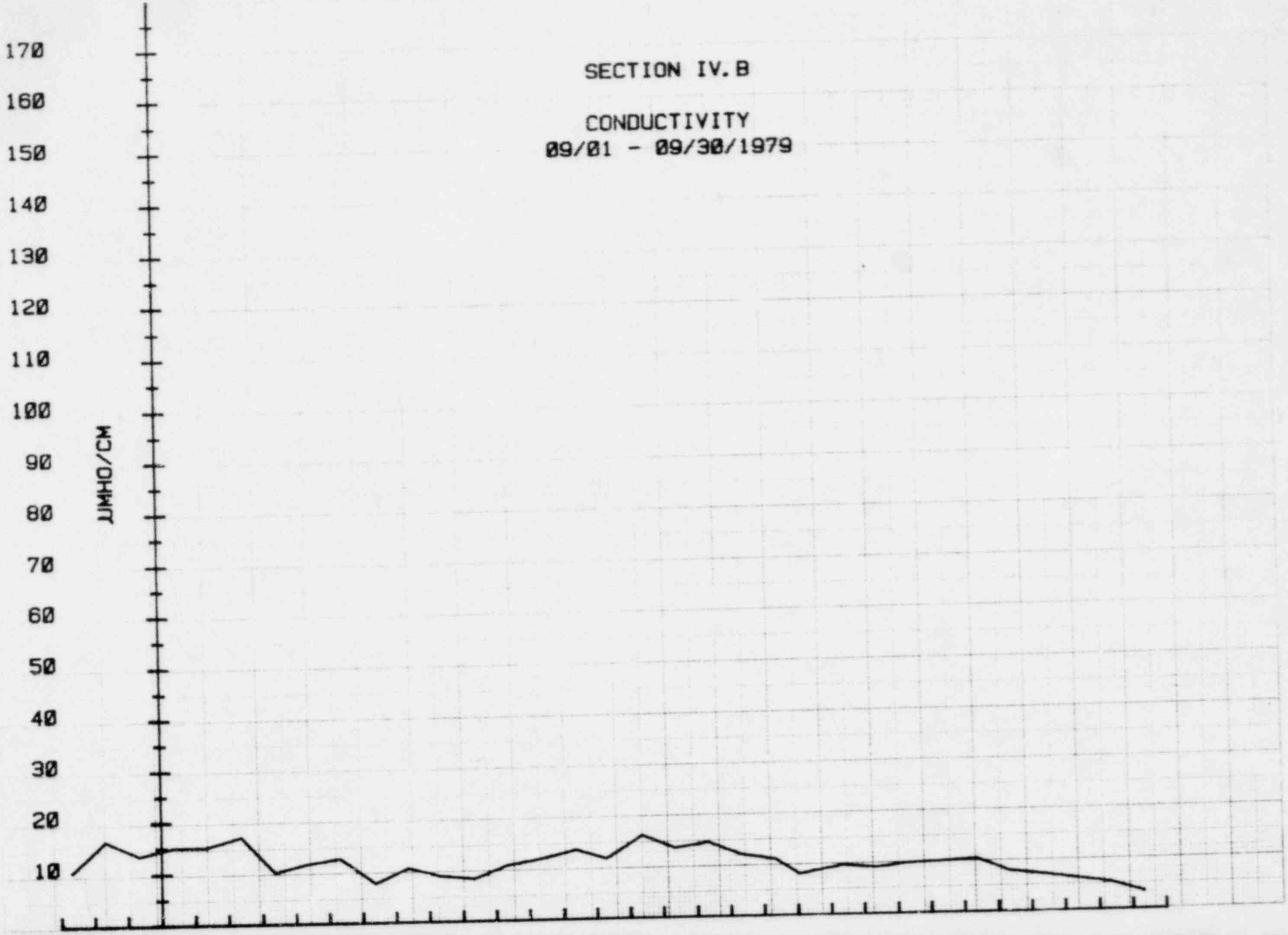
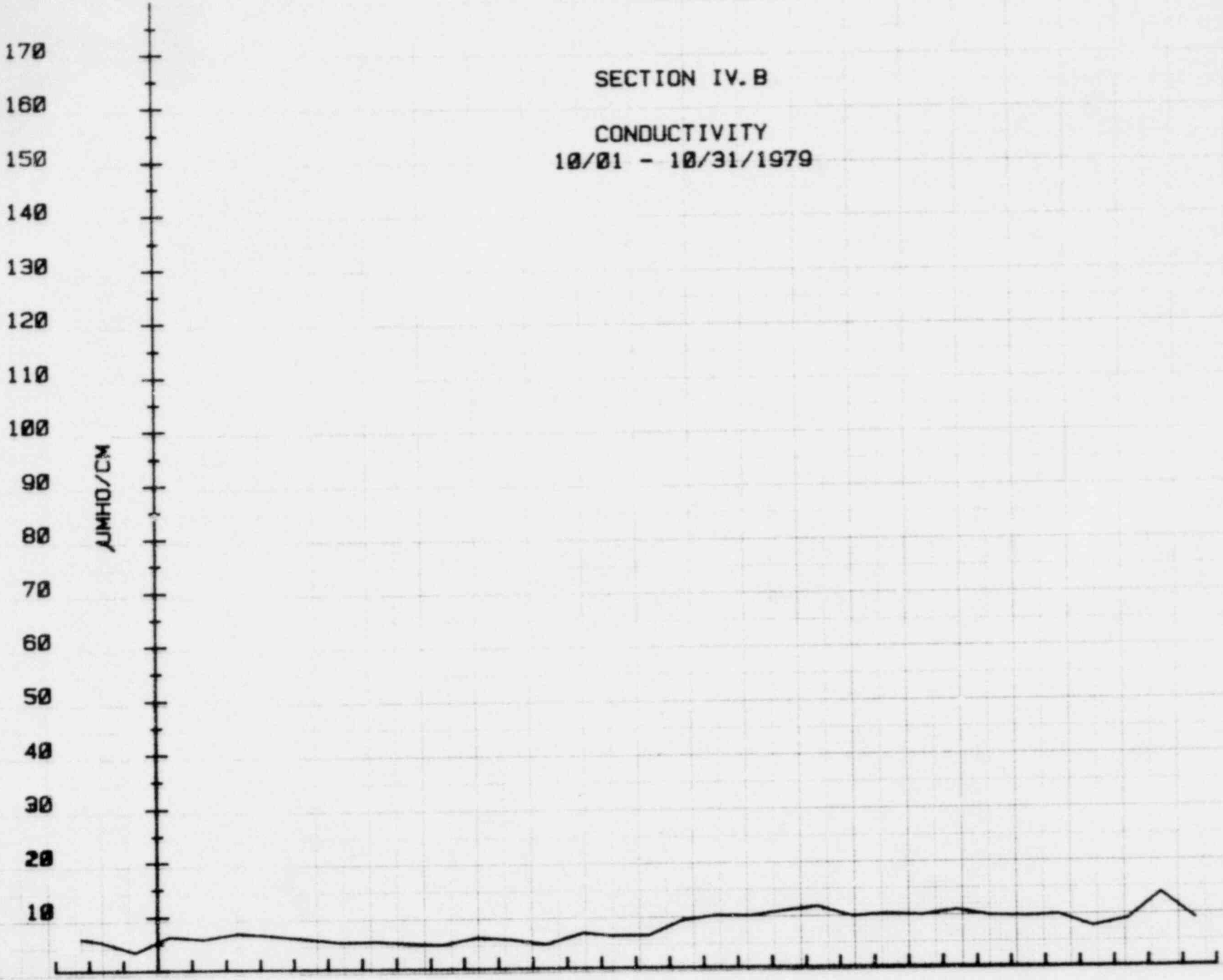

SECTION IV. B
CONDUCTIVITY
08/01 - 8/31/1979
µMHO/CM
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10

FIGURE B.10


SECTION IV.B

CONDUCTIVITY
09/01 - 09/30/1979

FIGURE B.11



SECTION IV.B

CONDUCTIVITY
10/01 - 10/31/1979

FIGURE B.12

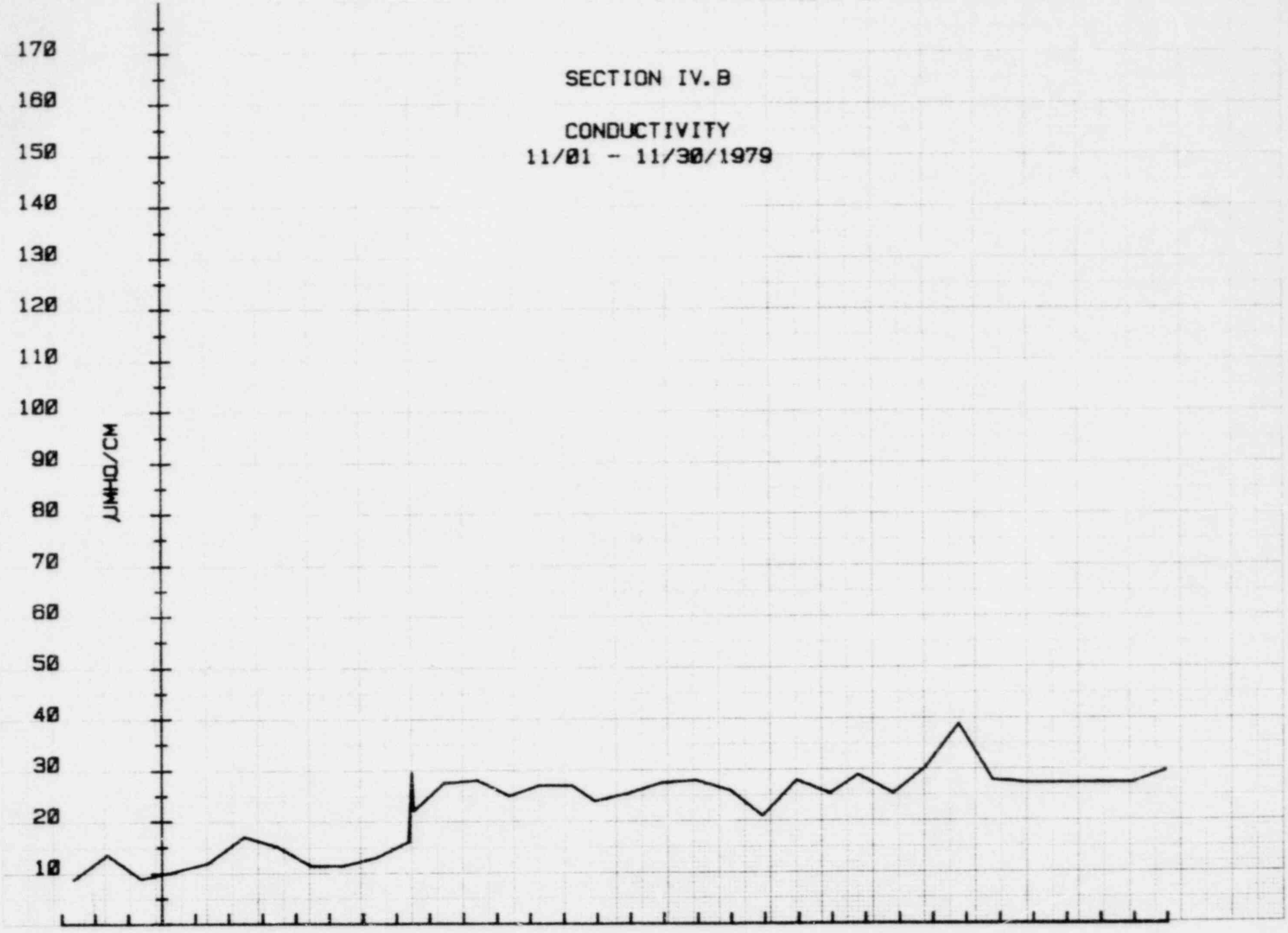

SECTION IV.B
CONDUCTIVITY
11/01 - 11/30/1979
µMHO/CM
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10

FIGURE B.13

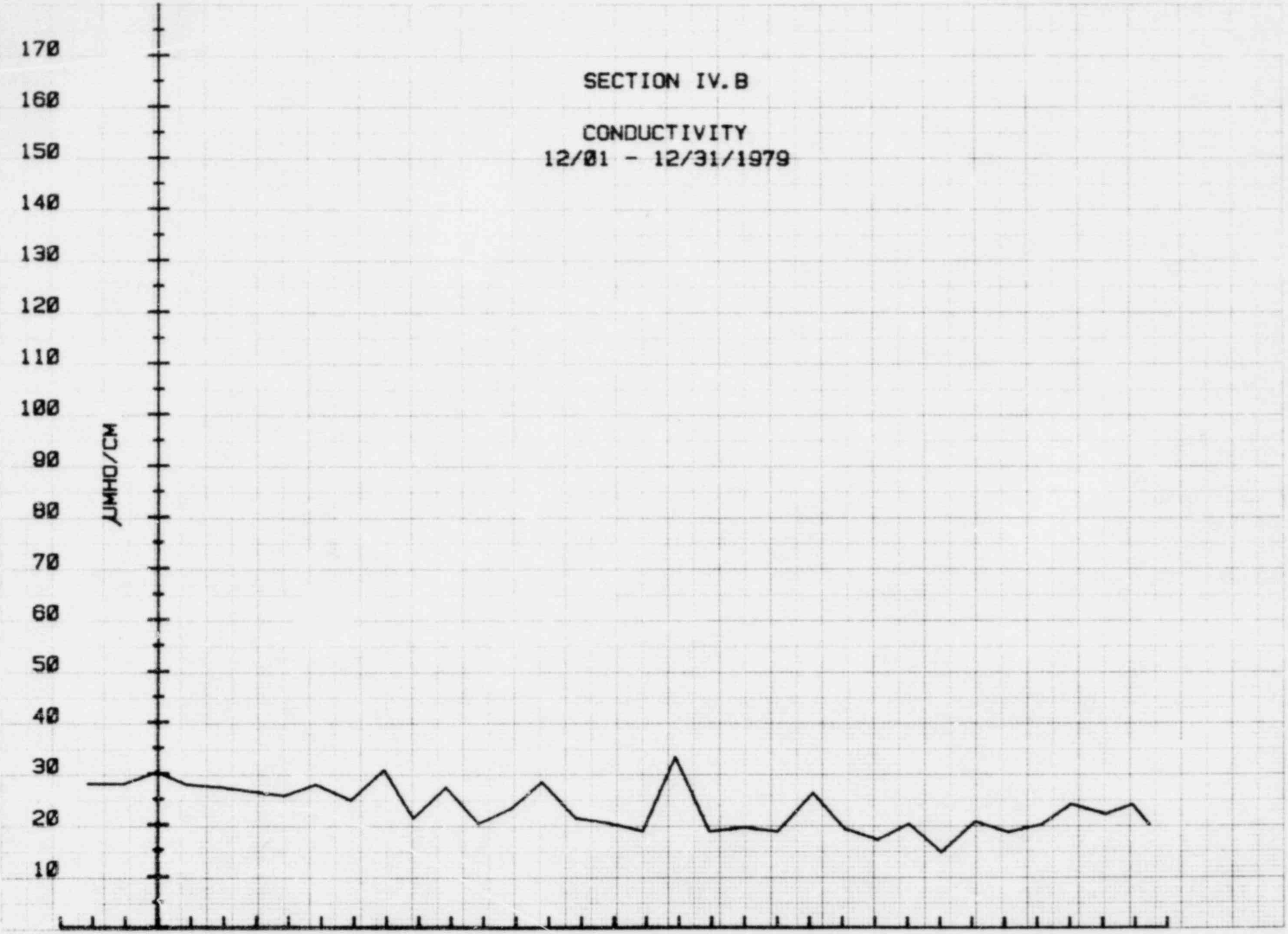
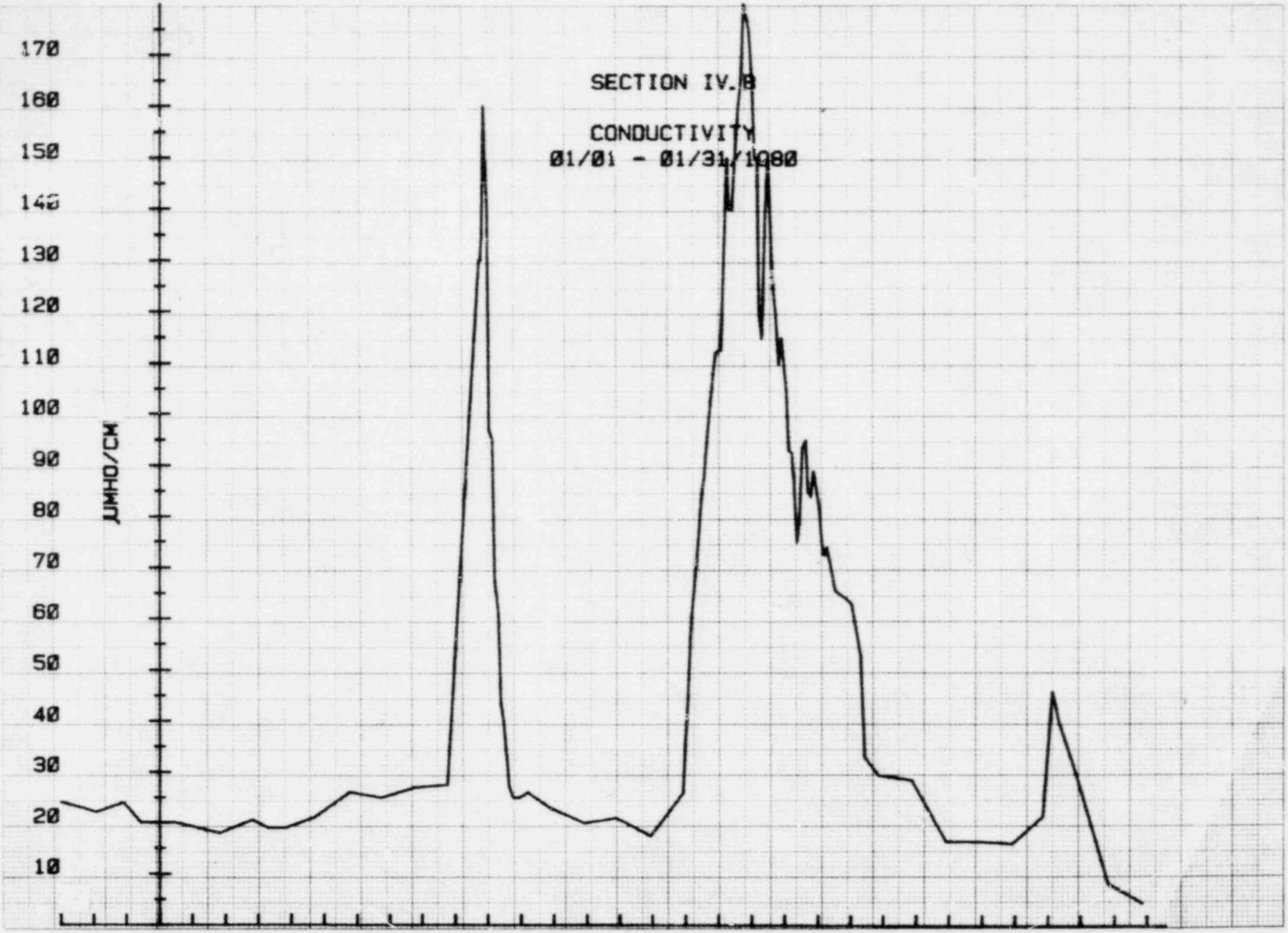

SECTION IV.B
CONDUCTIVITY
12/01 - 12/31/1979
µMHO/CM
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10

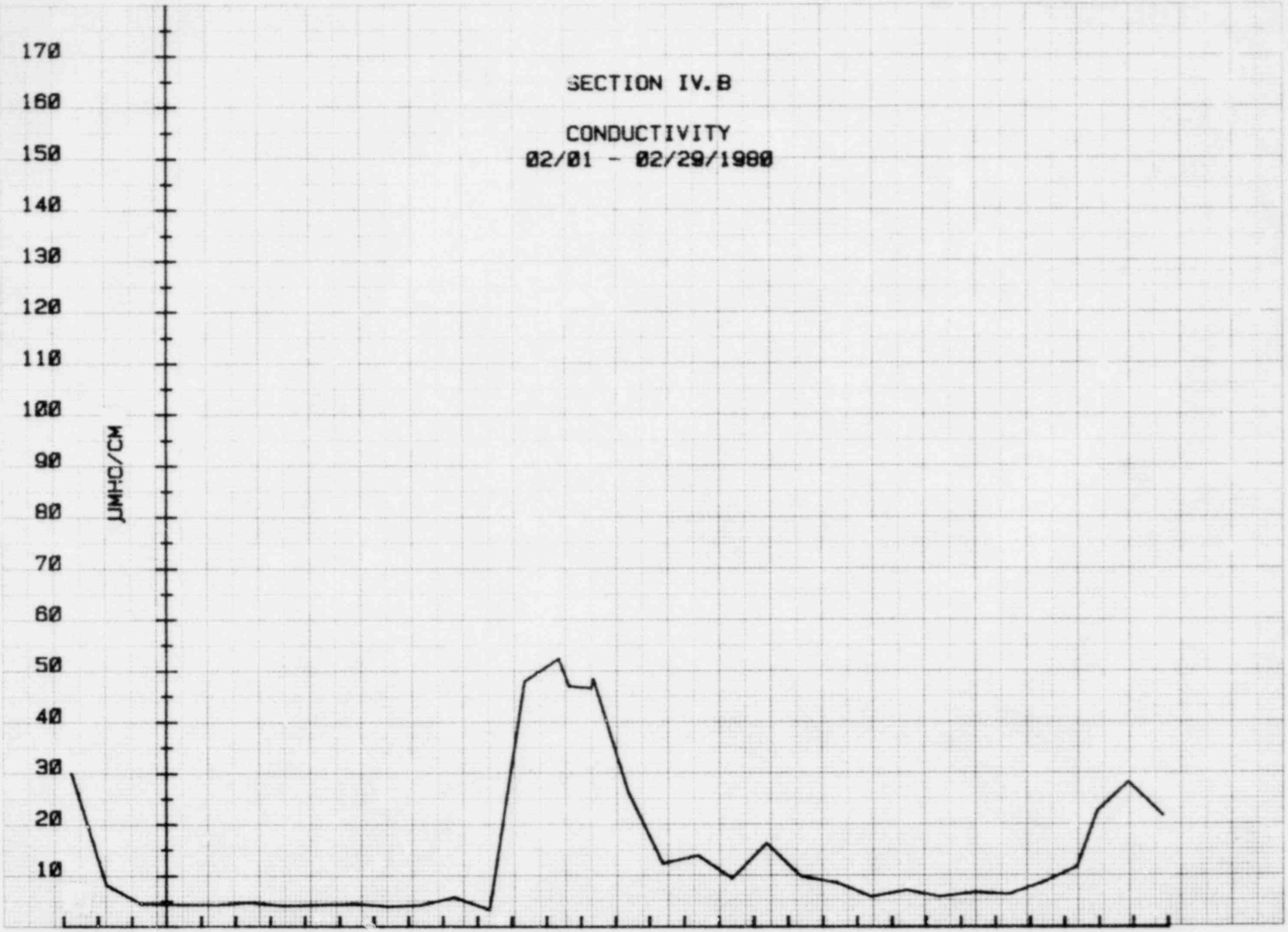
FIGURE B.14



SECTION IV.B

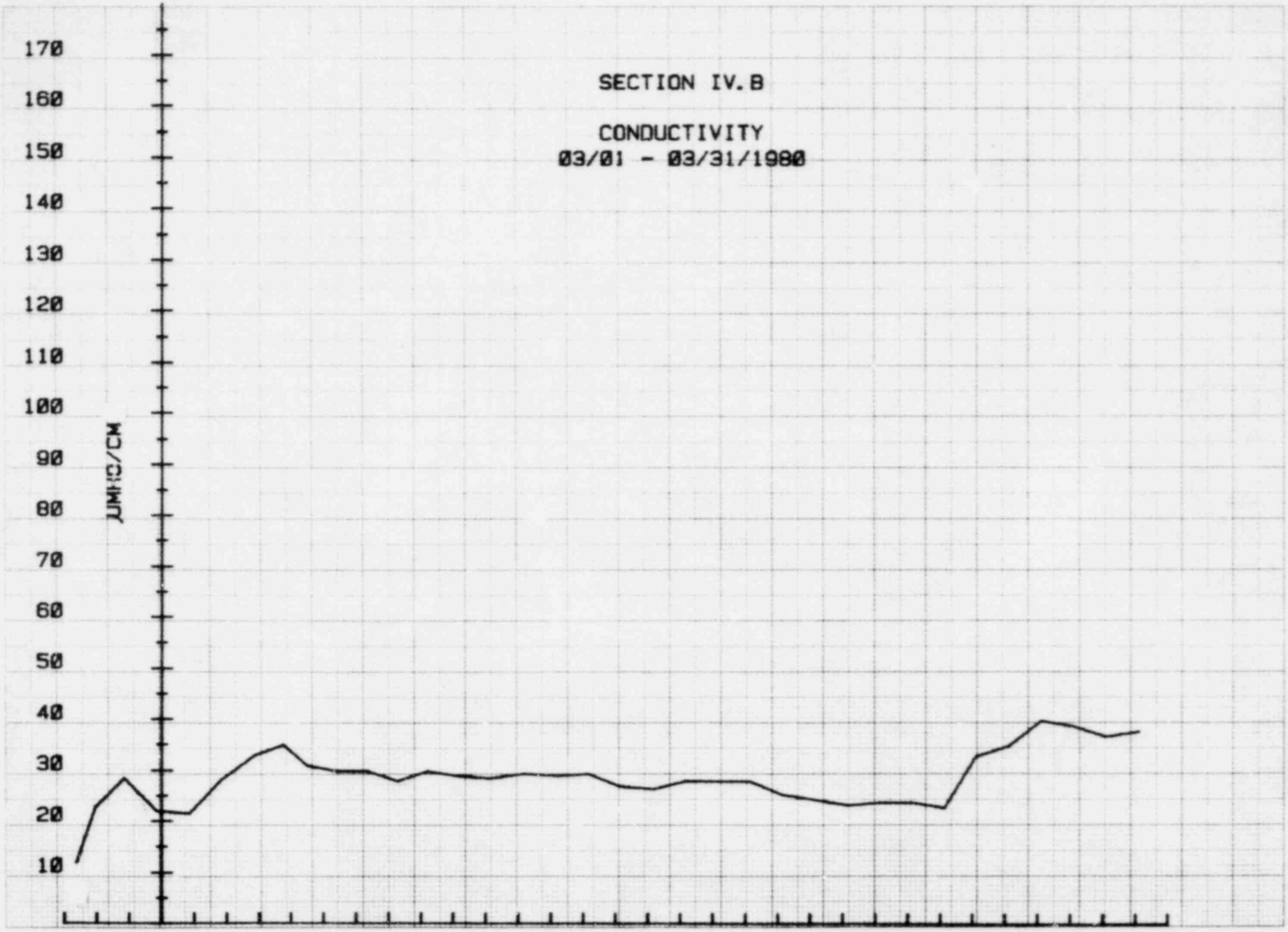
CONDUCTIVITY
01/01 - 01/31/1980

FIGURE B.15


SECTION IV.B

CONDUCTIVITY
02/01 - 02/29/1980

FIGURE B.16


SECTION IV. B
CONDUCTIVITY
03/01 - 03/31/1980
UMHO/CM
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10

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

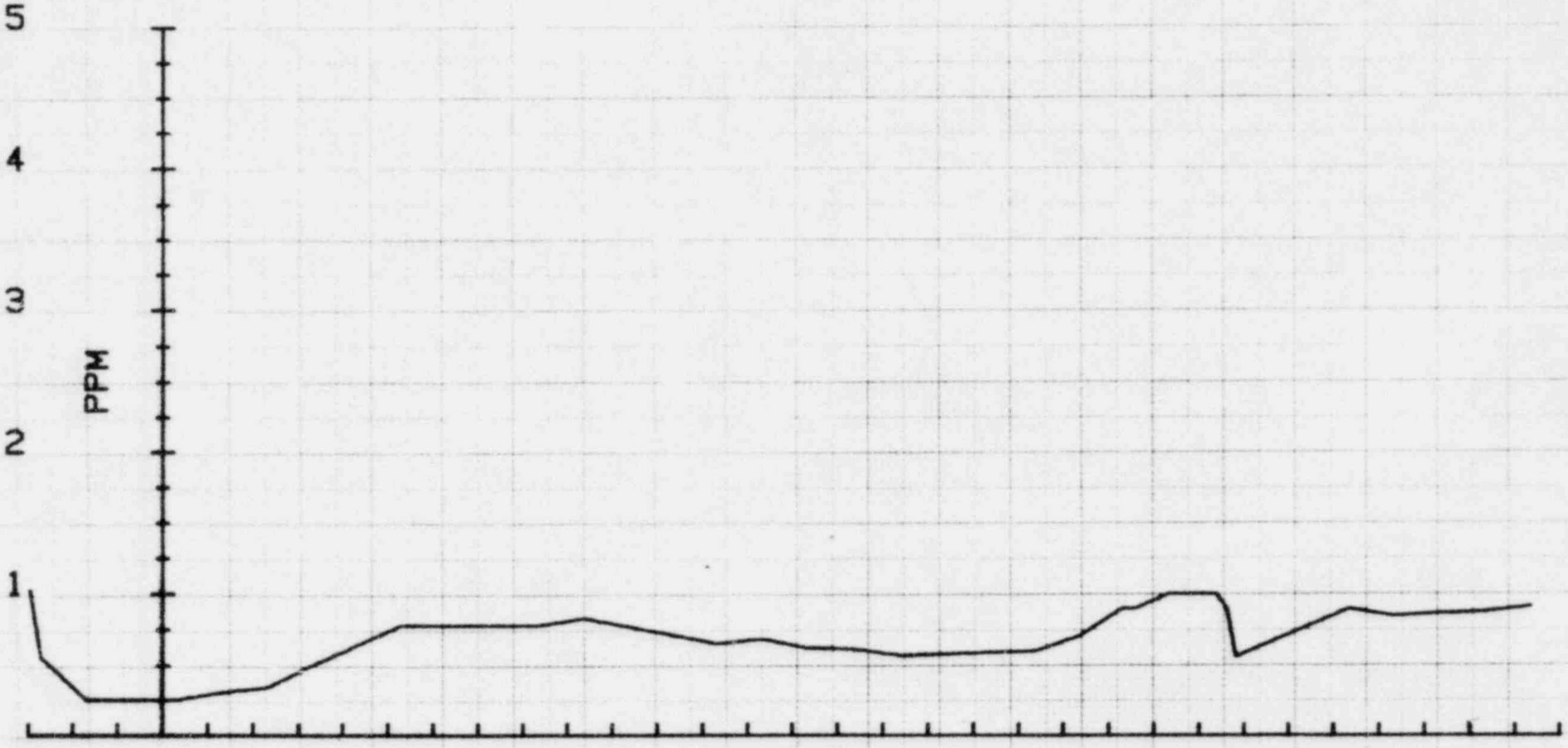


FIGURE B.18

SECTION IV.B

LITHIUM
09/01 - 09/30/1979

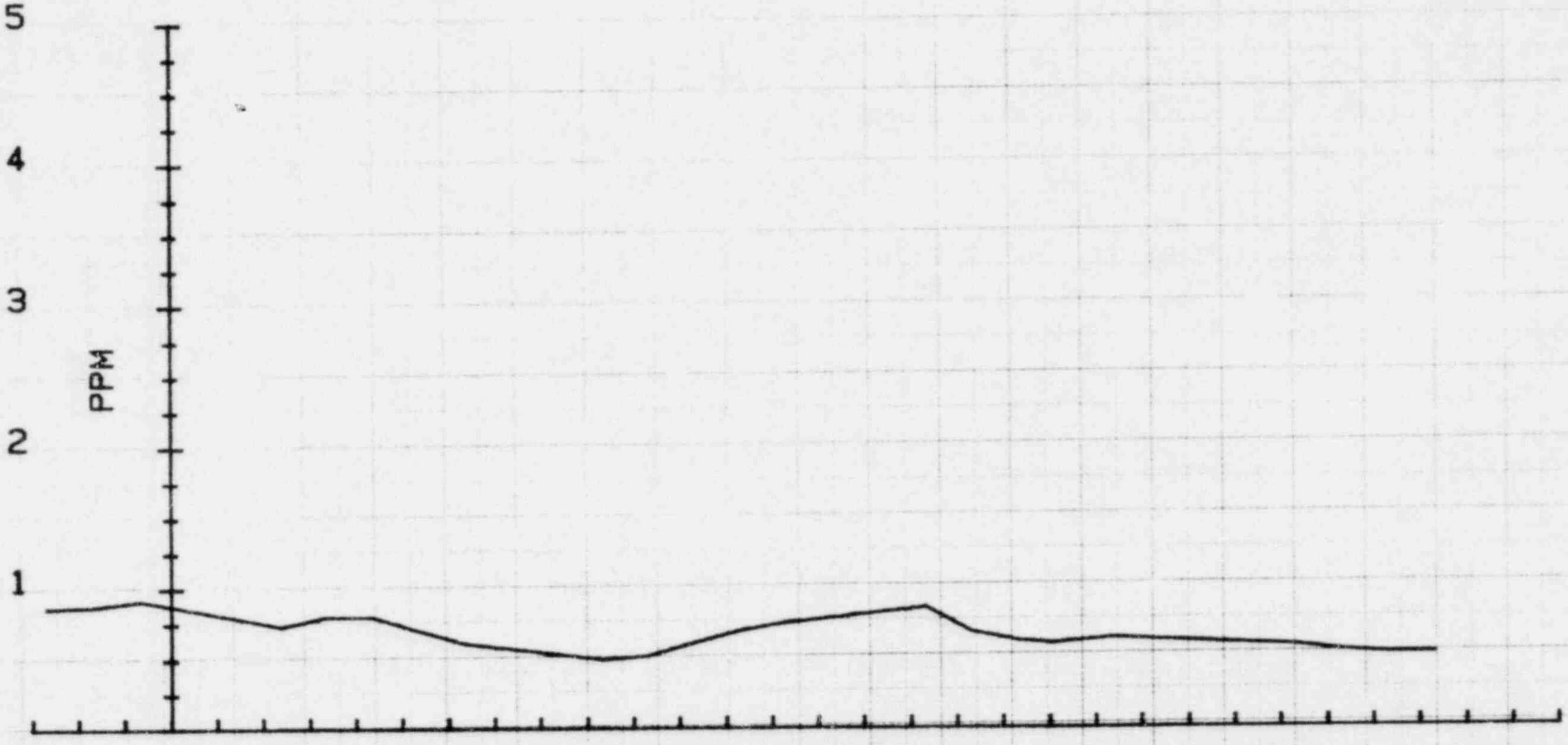


FIGURE B.19

SECTION IV.B

LITHIUM
10/01 - 10/31/1979

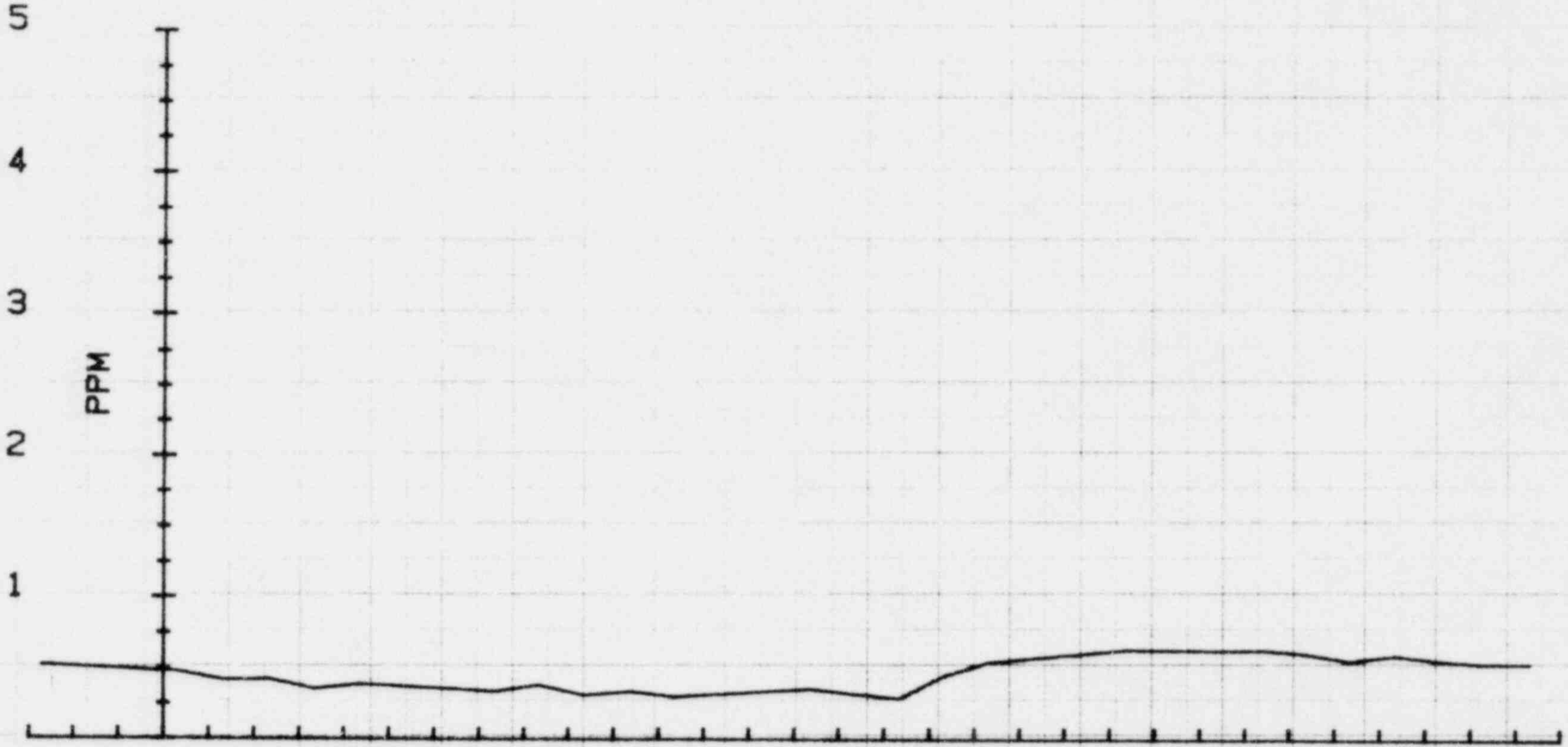


FIGURE B. 20

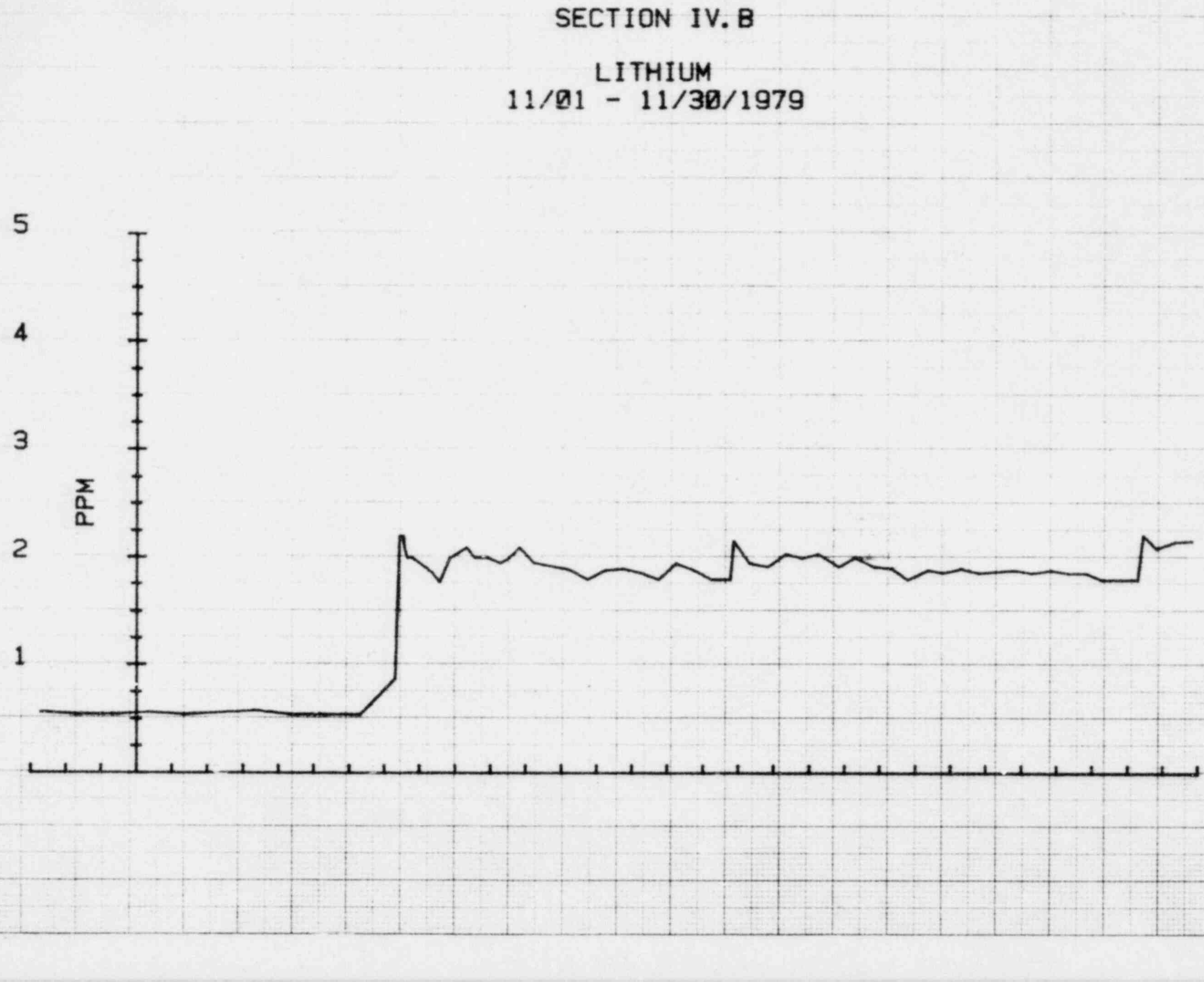


FIGURE B.21

SECTION IV.B

LITHIUM
12/01 - 12/31/1979

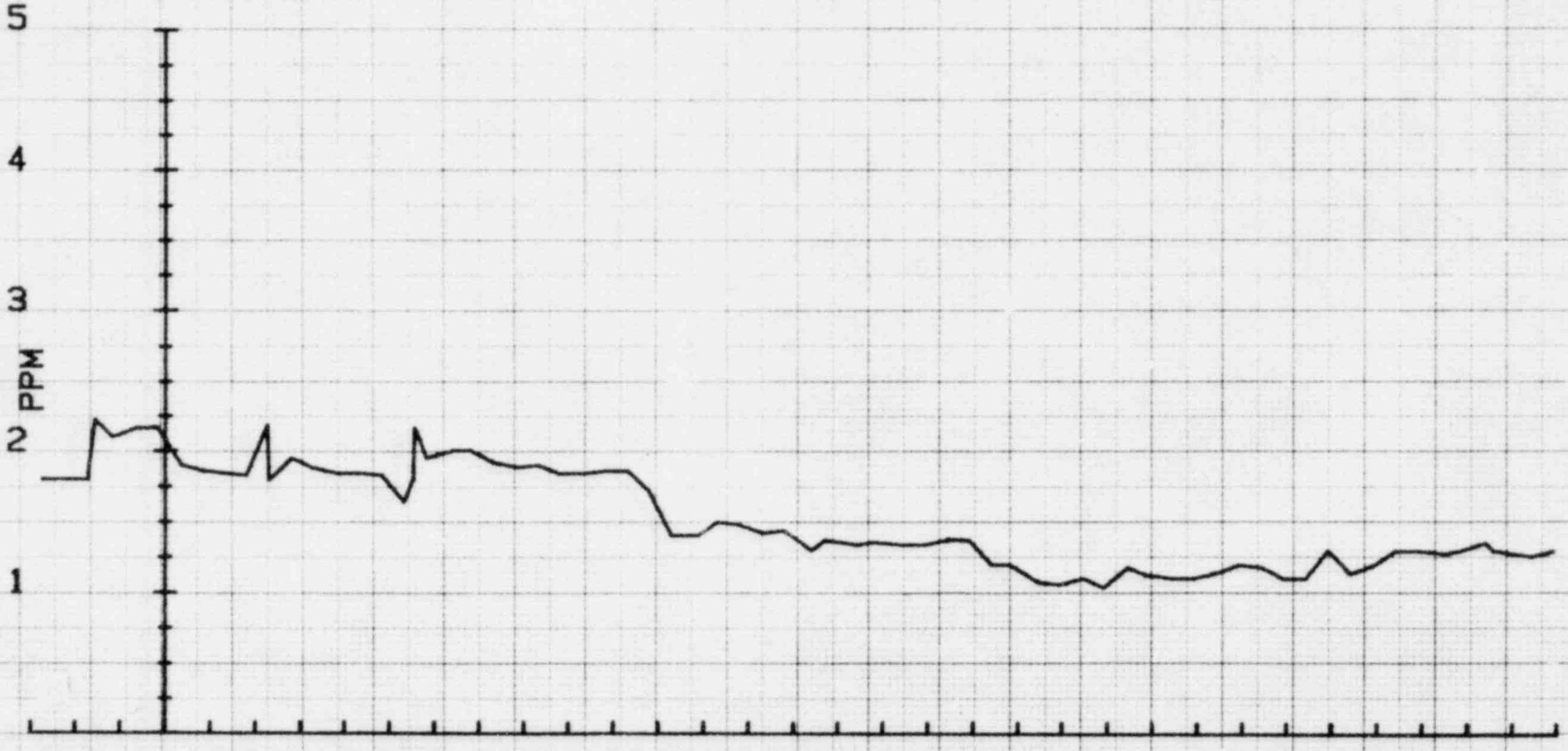


FIGURE B.22

SECTION IV.B

LITHIUM
01/01 - 01/31/1980

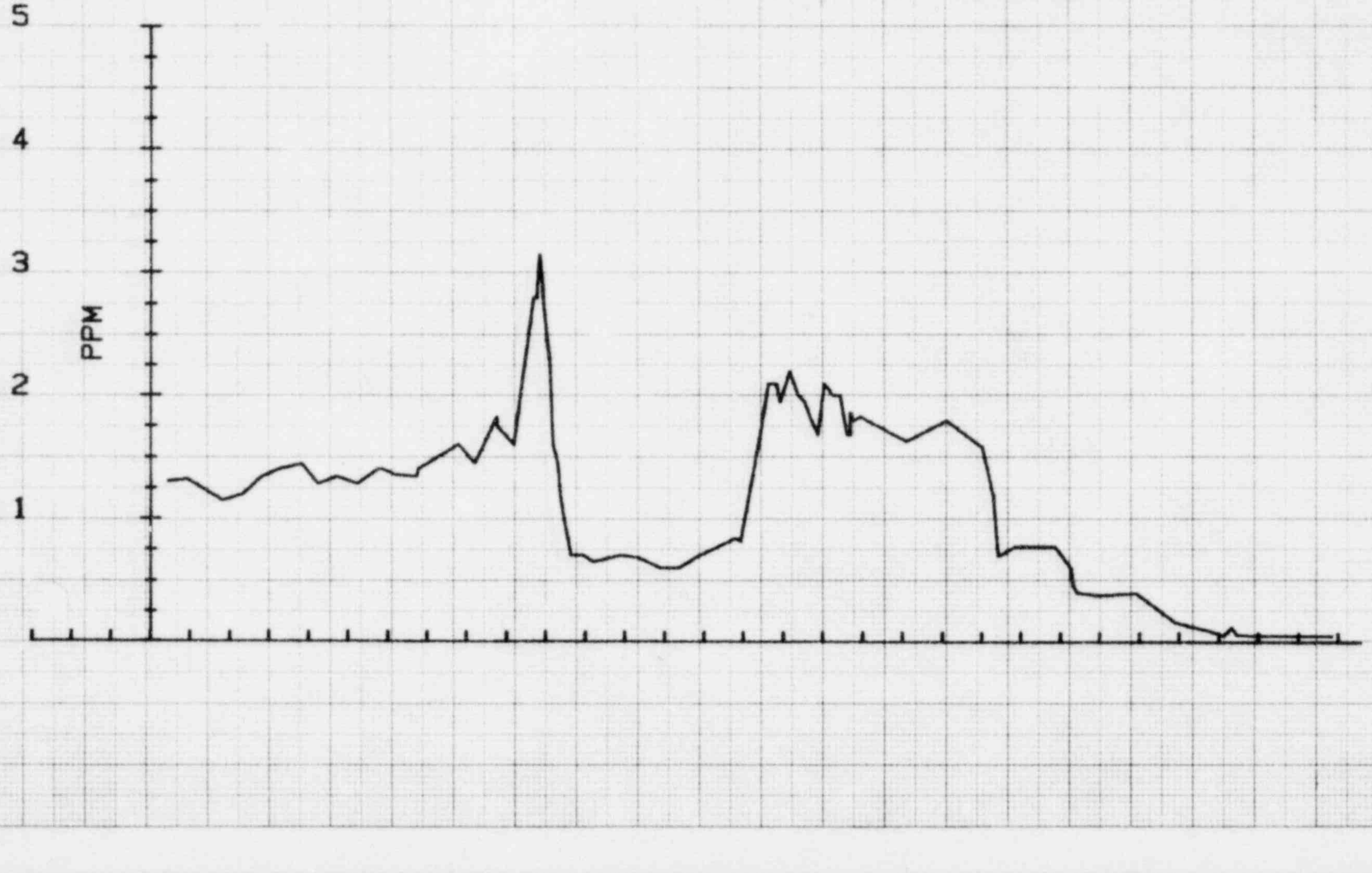


FIGURE B.23

SECTION IV.B

LITHIUM
02/01 - 02/29/1980

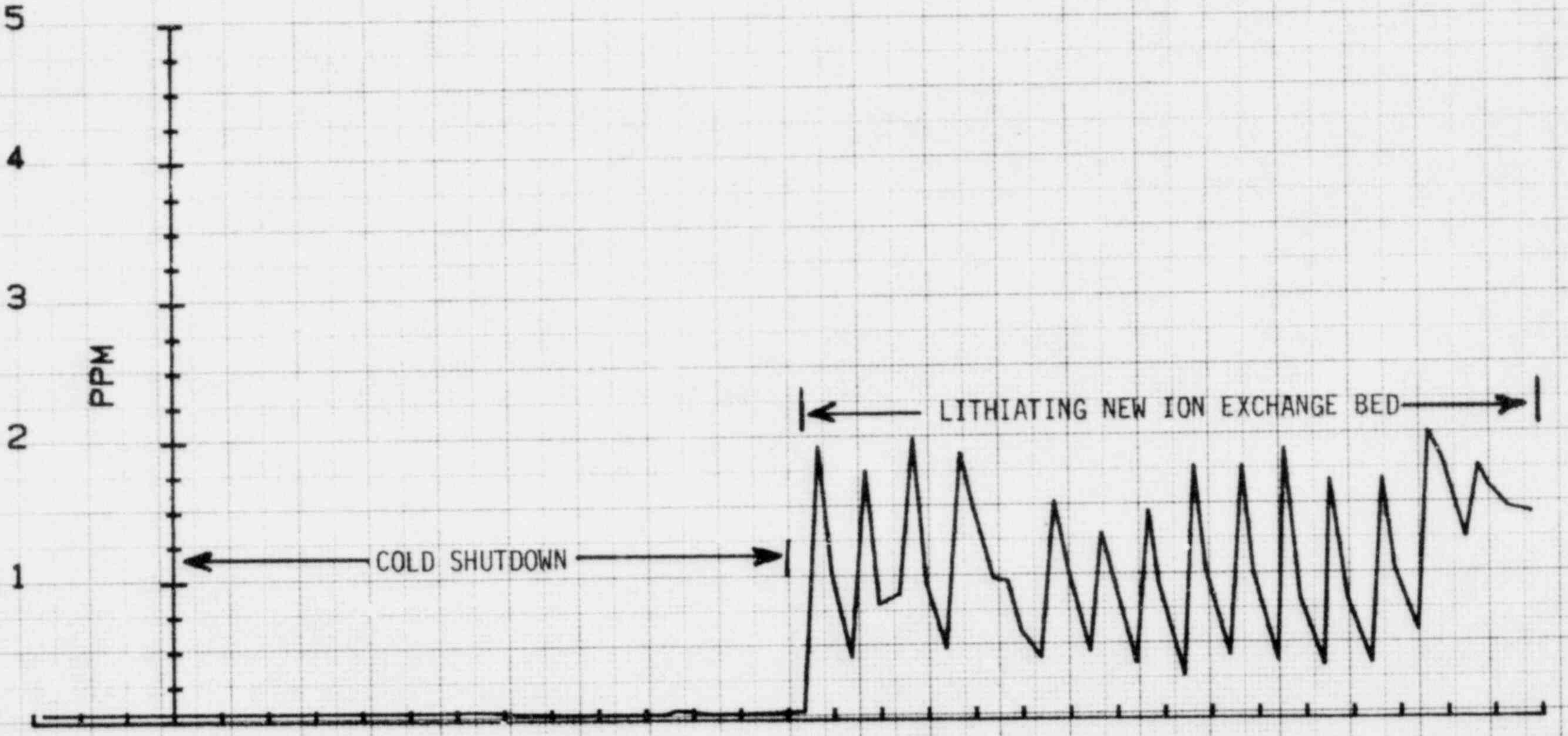
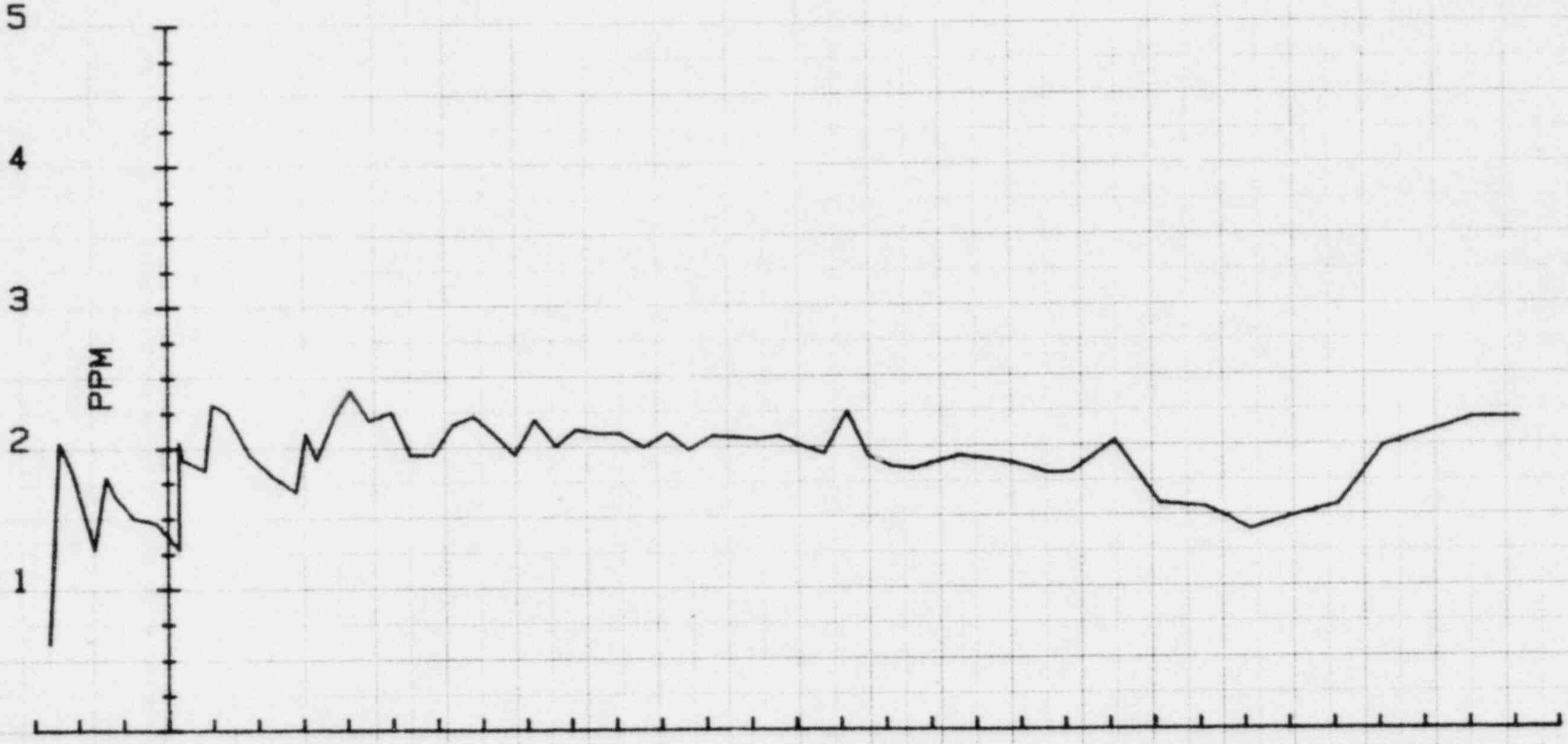


FIGURE B.24

SECTION IV.B

LITHIUM
03/01 - 03/31/1980



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 perioxide treatment is further discussed in Section IV.B.2.d.

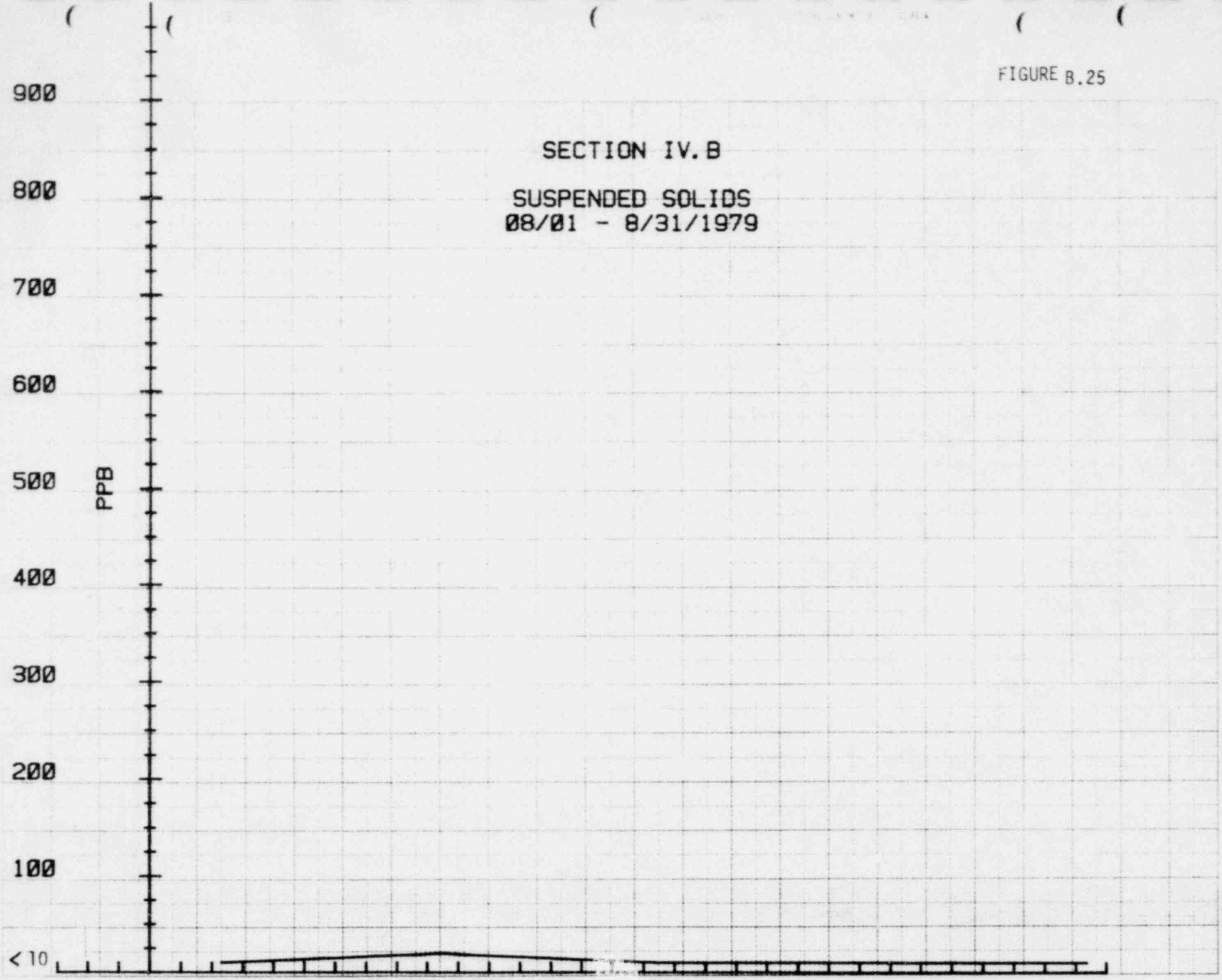


FIGURE B.25

SECTION IV.B

SUSPENDED SOLIDS
08/01 - 8/31/1979

FIGURE B.26

SECTION IV.B

SUSPENDED SOLIDS
09/01 - 09/30/1979

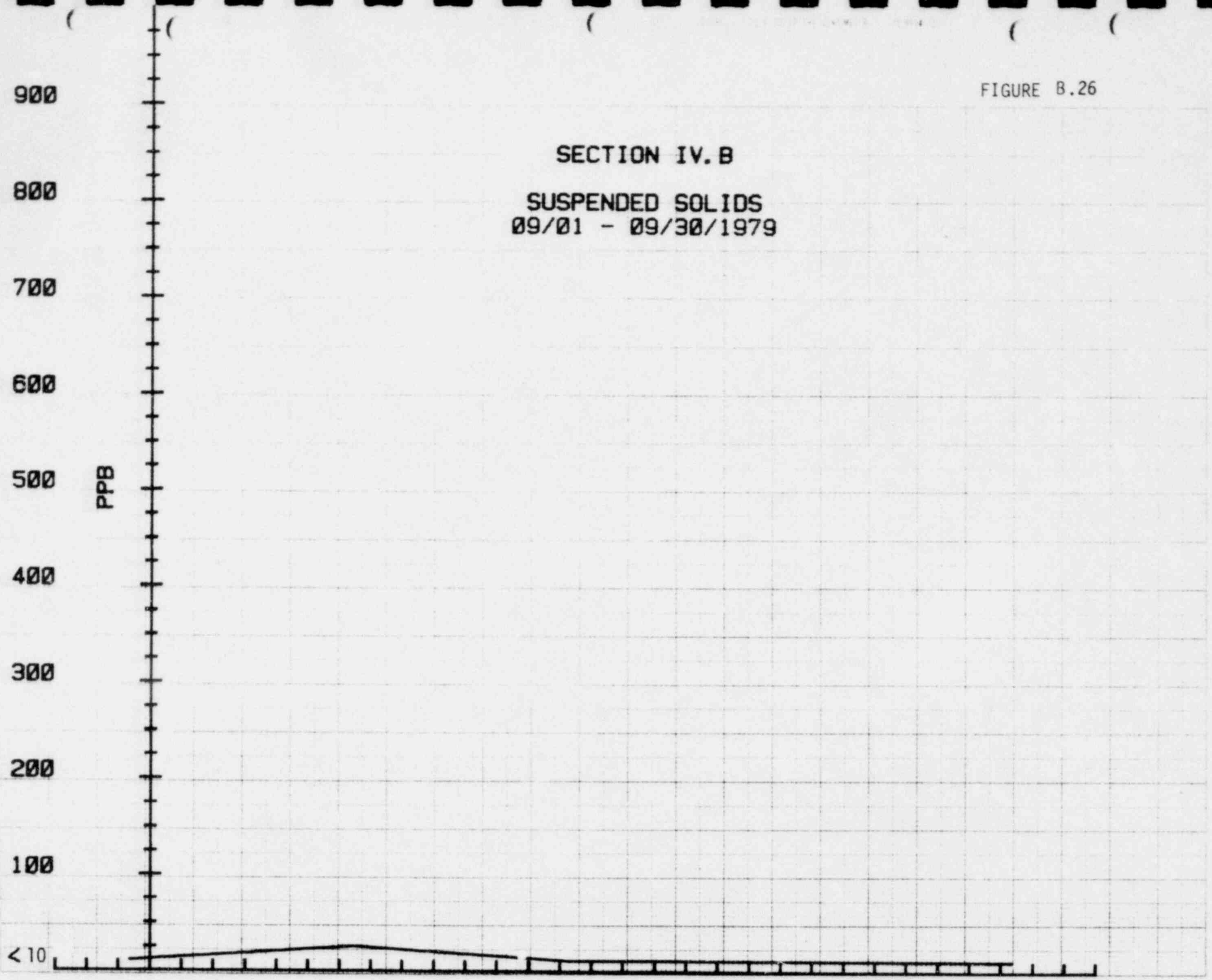


FIGURE B.27

SECTION IV.B

SUSPENDED SOLIDS
10/01 - 10/31/1979

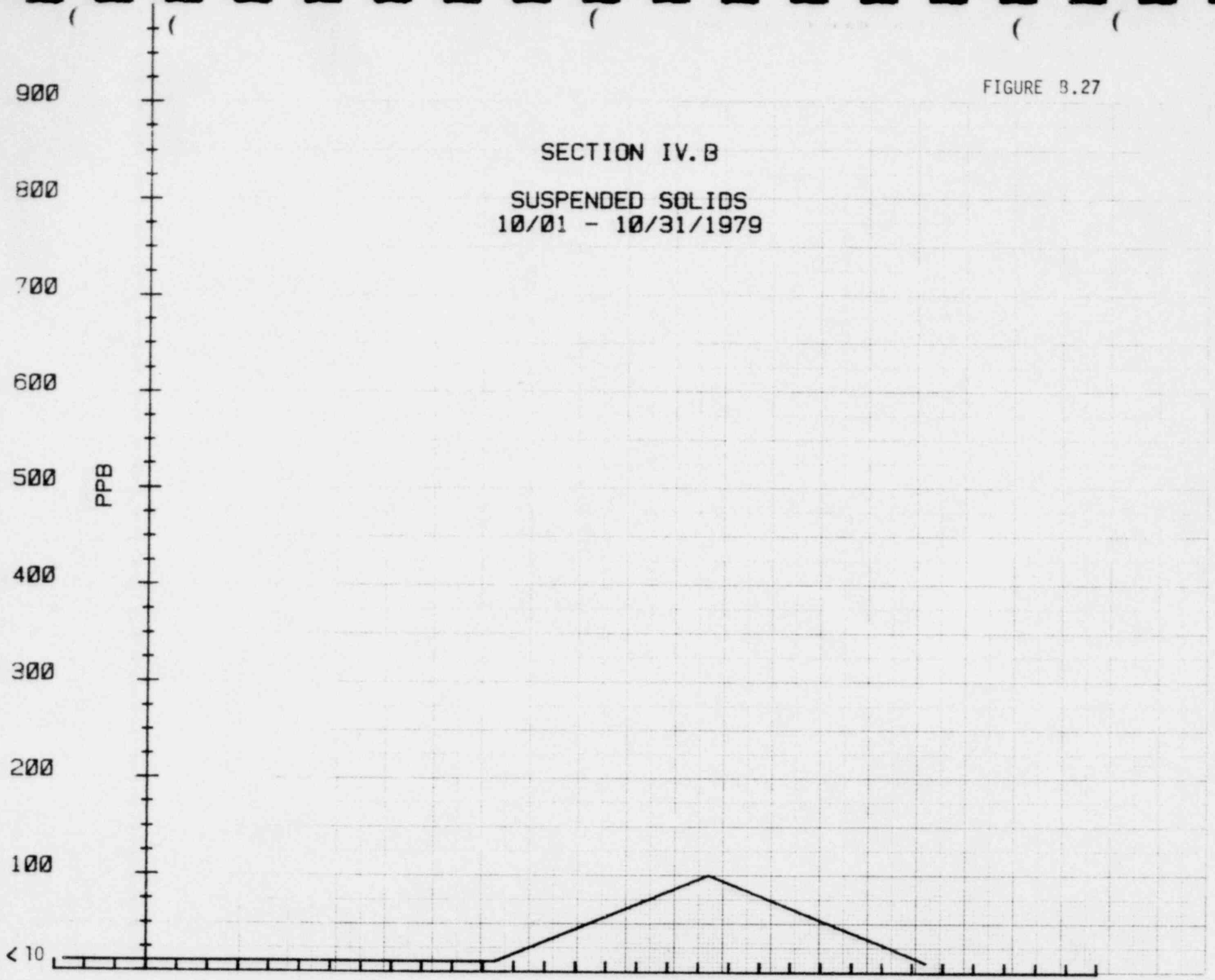
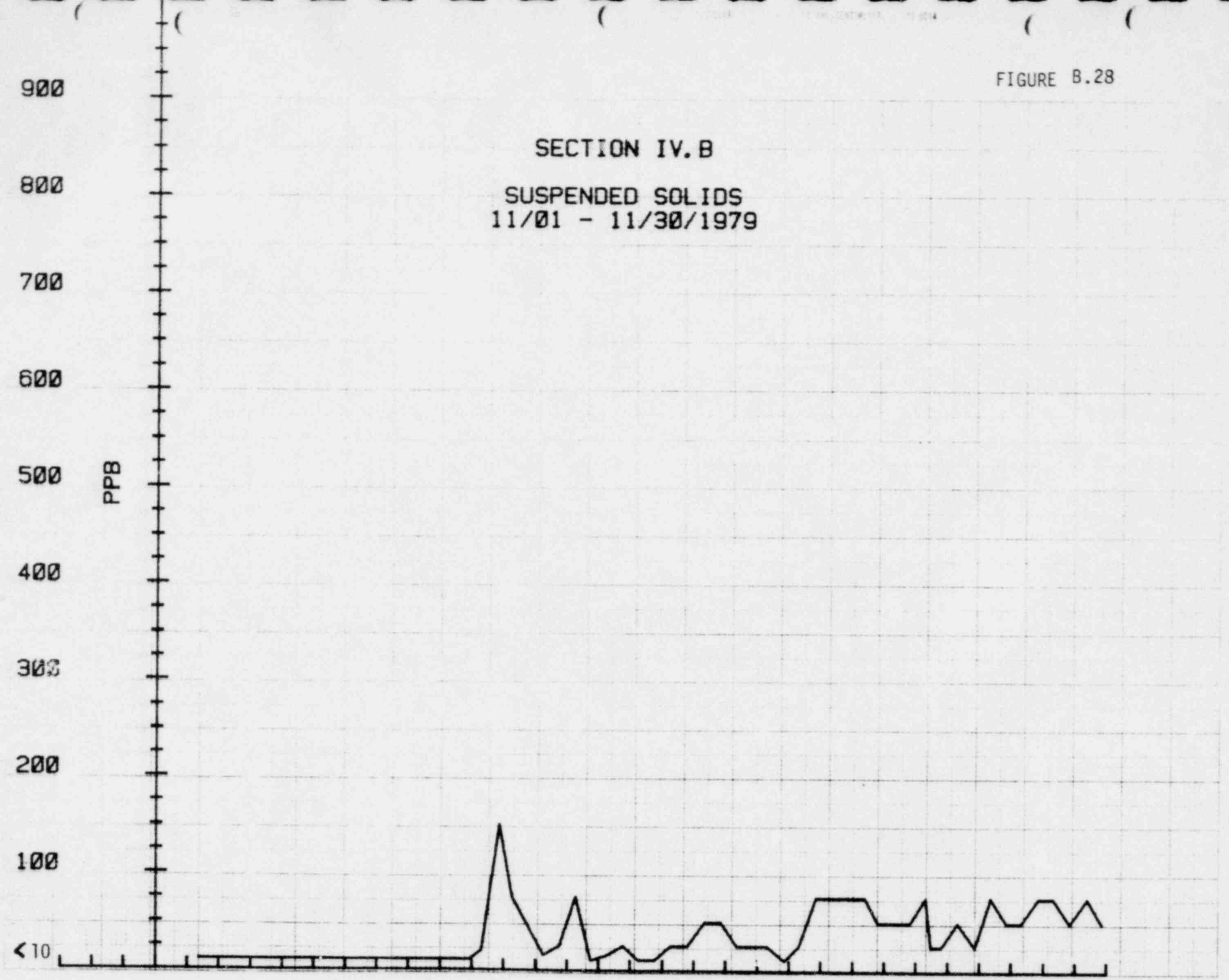


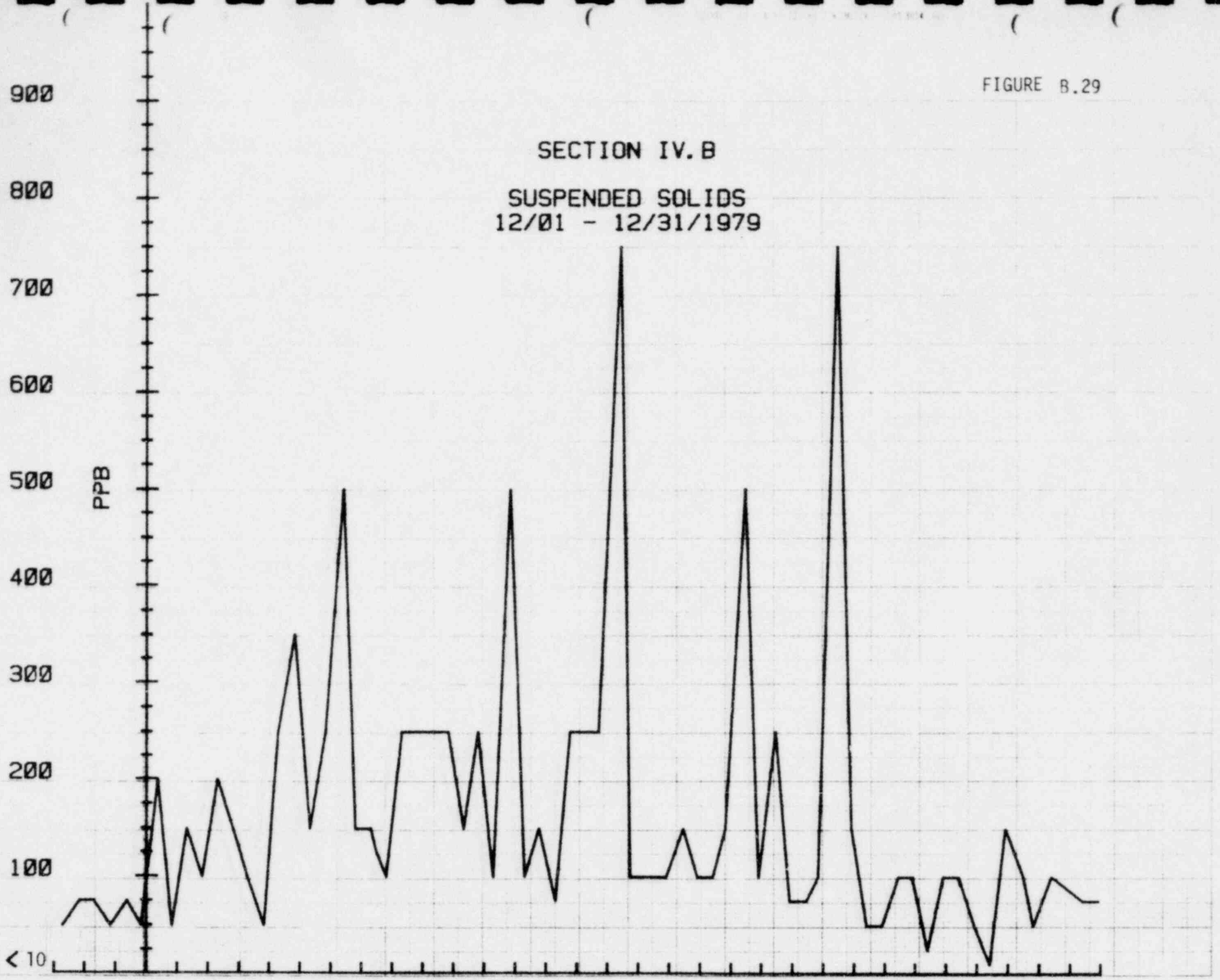
FIGURE B.28



SECTION IV.B

SUSPENDED SOLIDS
11/01 - 11/30/1979

FIGURE B.29



SECTION IV.B

SUSPENDED SOLIDS
12/01 - 12/31/1979

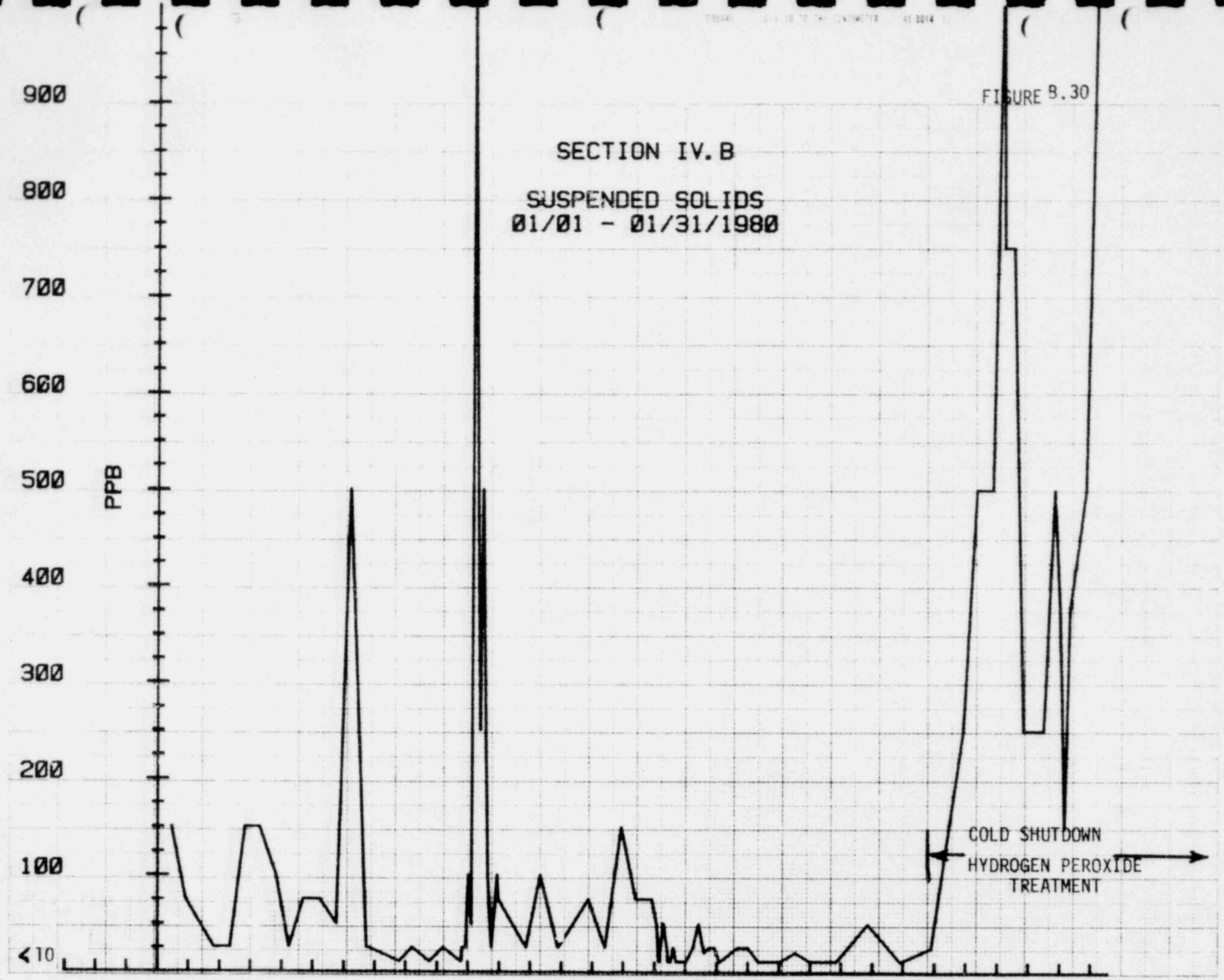
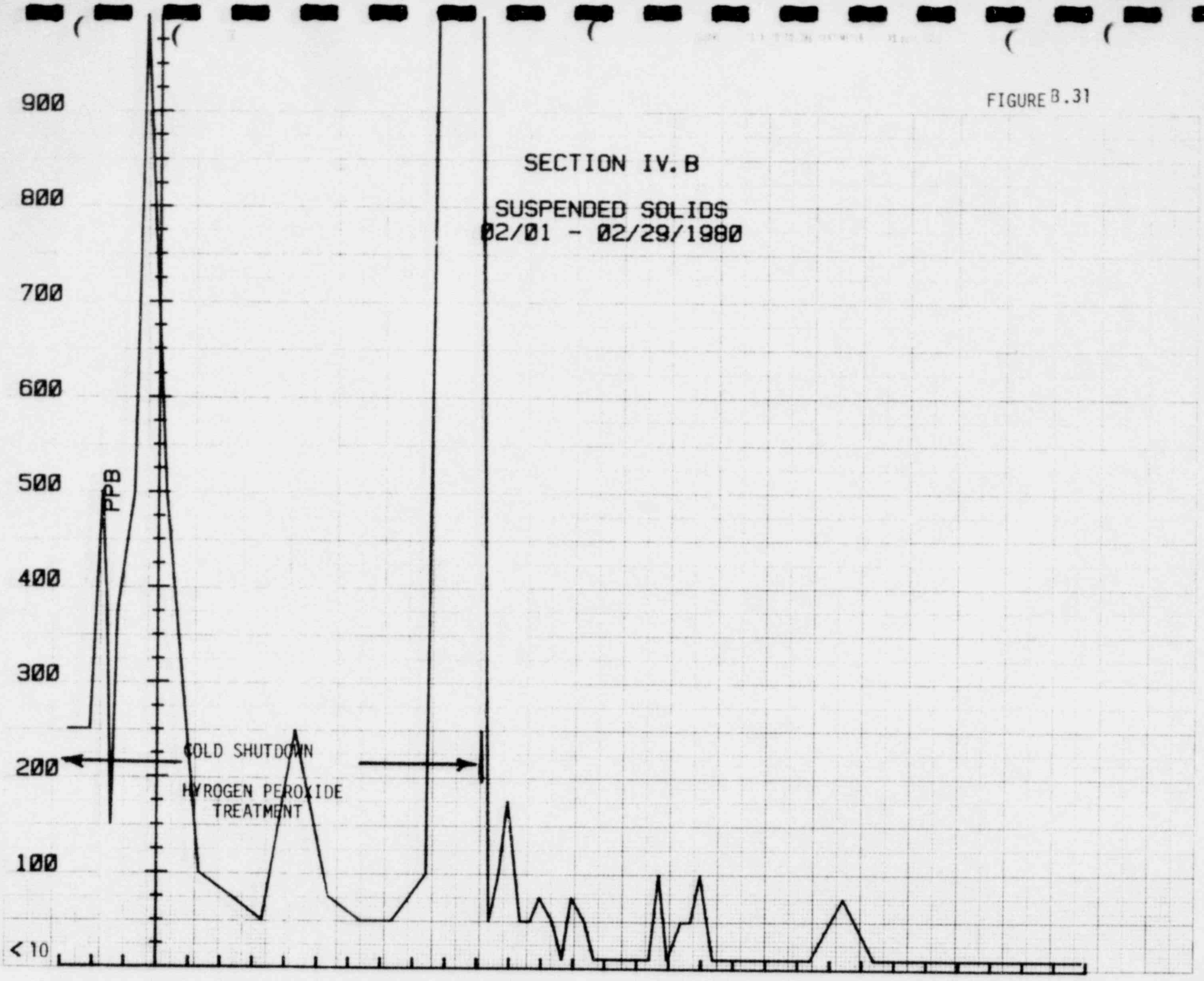


FIGURE B.30

SECTION IV.B

SUSPENDED SOLIDS
01/01 - 01/31/1980

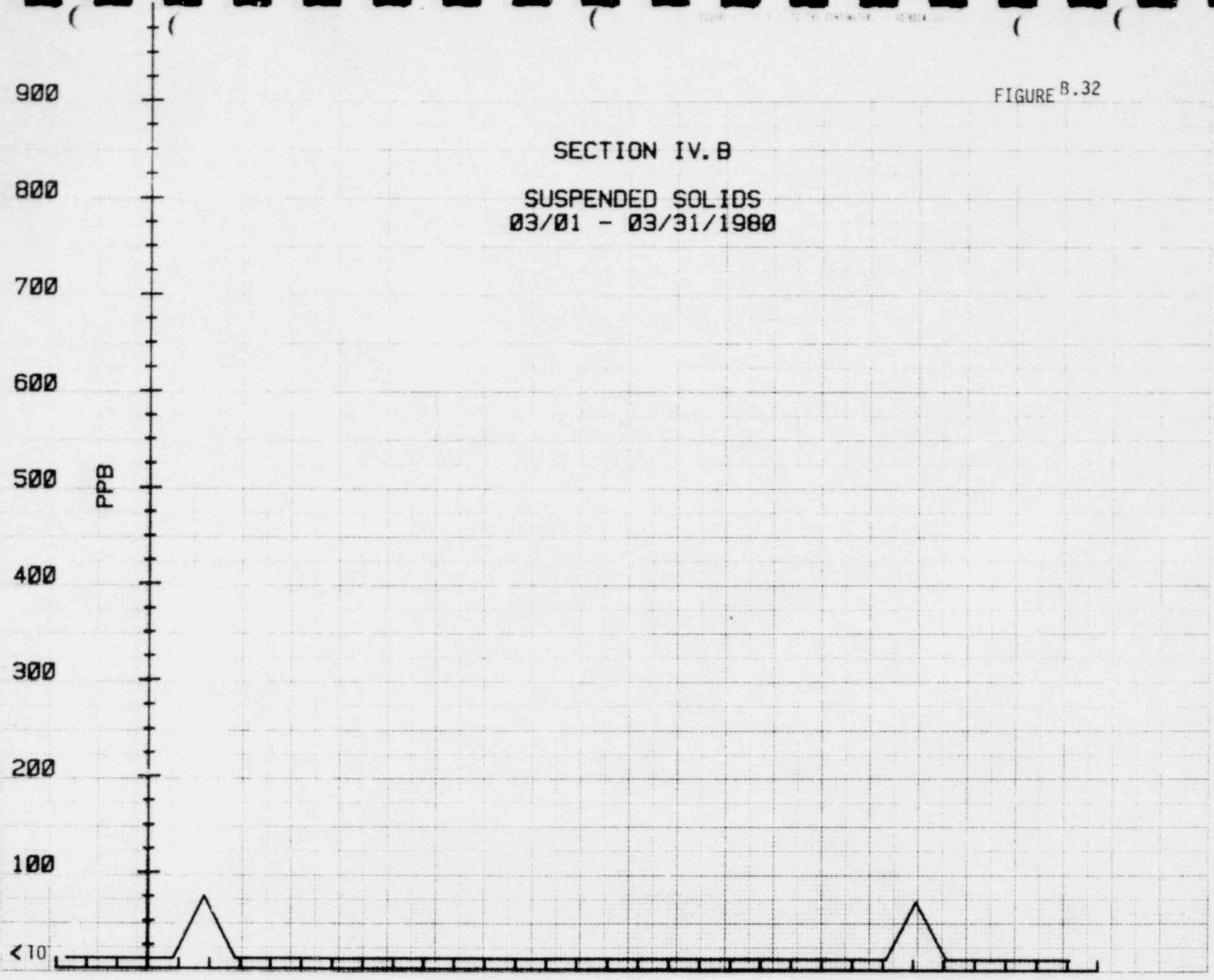
FIGURE B.31



SECTION IV.B

SUSPENDED SOLIDS
02/01 - 02/29/1980

FIGURE B.32



SECTION IV.B

SUSPENDED SOLIDS
03/01 - 03/31/1980

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

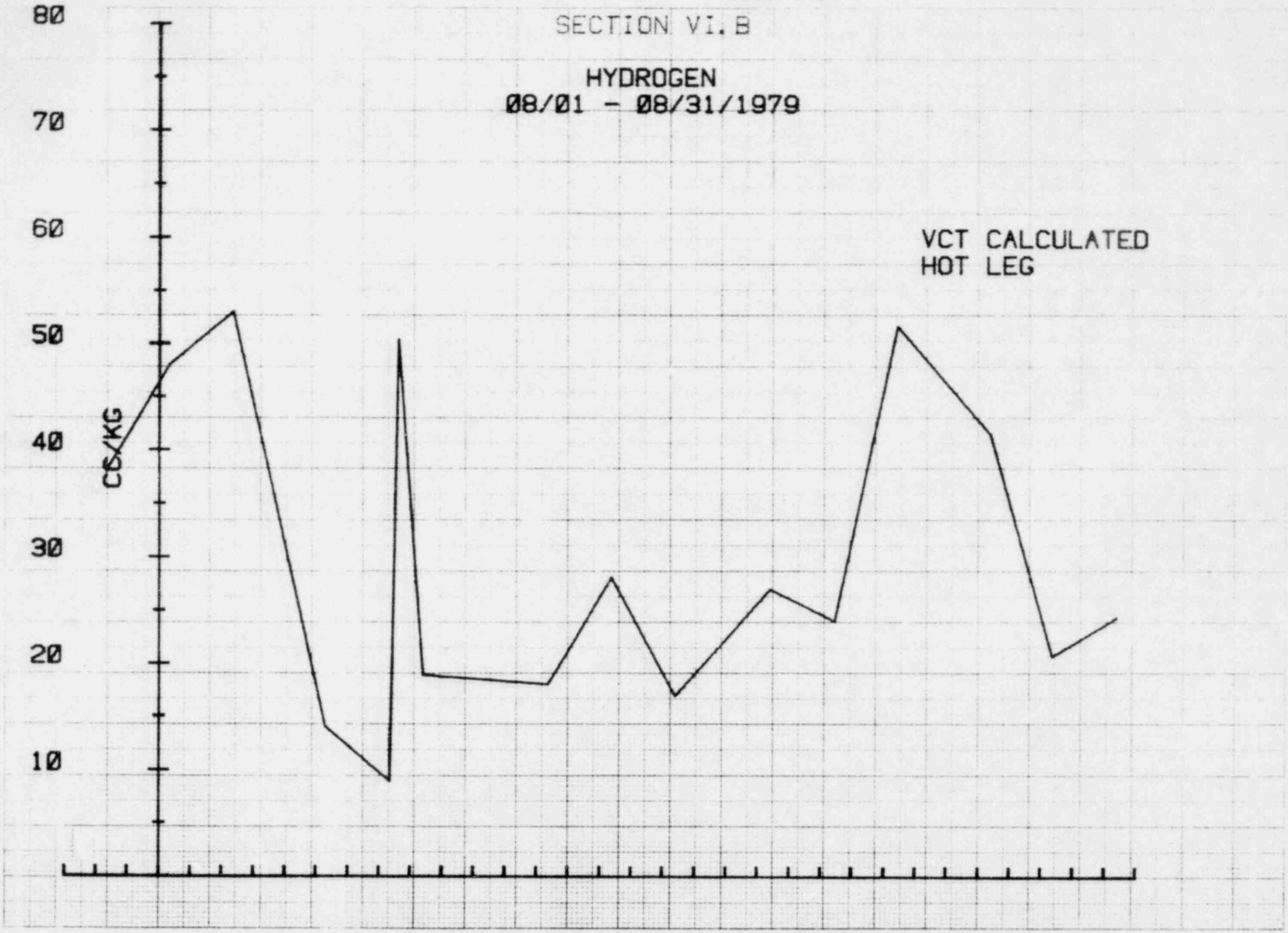

SECTION VI.B
HYDROGEN
08/01 - 08/31/1979
VCT CALCULATED
HOT LEG
CC/KG
80
70
60
50
40
30
20
10

FIGURE B.34

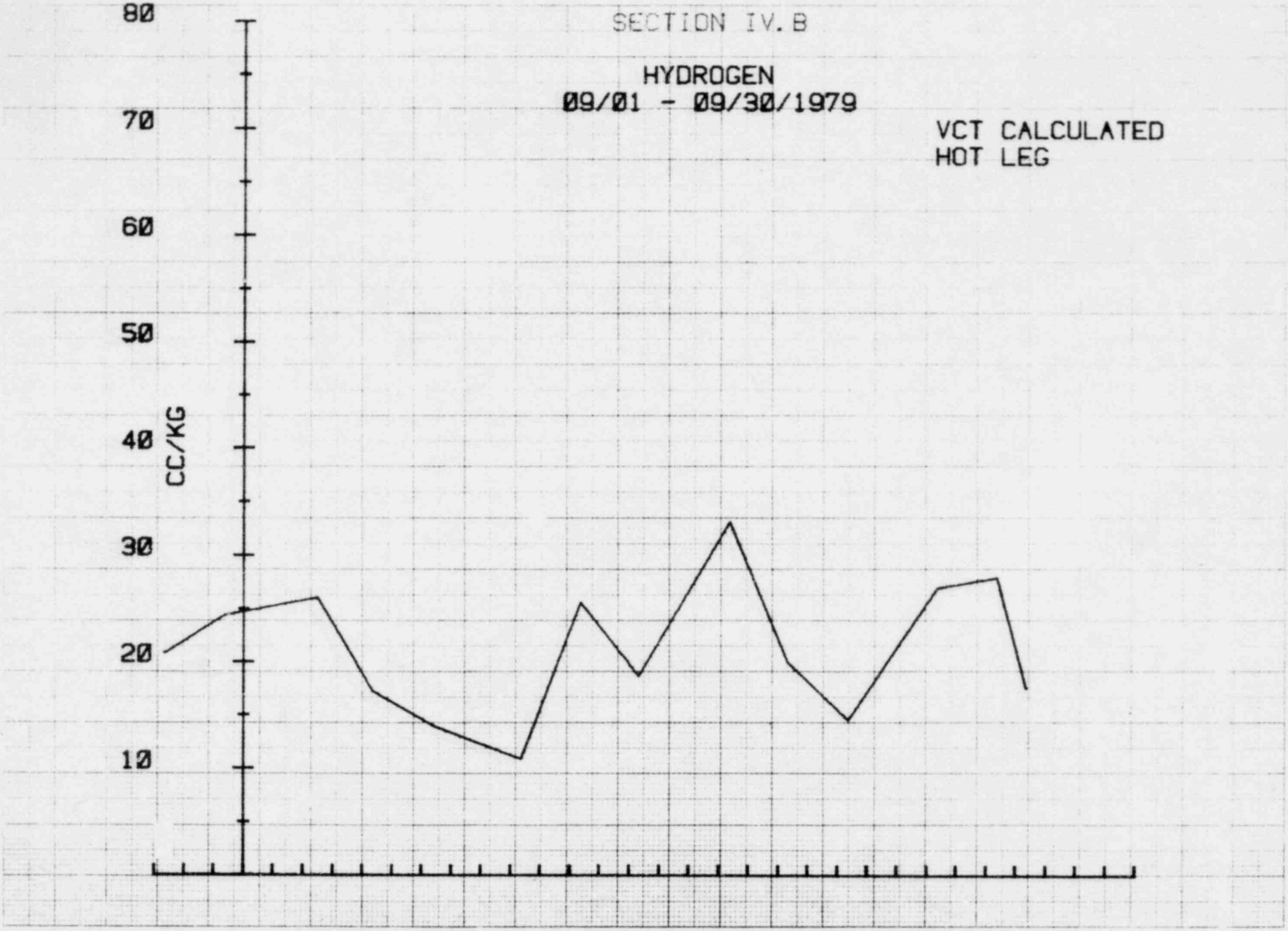

SECTION IV.B
HYDROGEN
09/01 - 09/30/1979
VCT CALCULATED
HOT LEG
CC/KG
80
70
60
50
40
30
20
10

FIGURE B.35

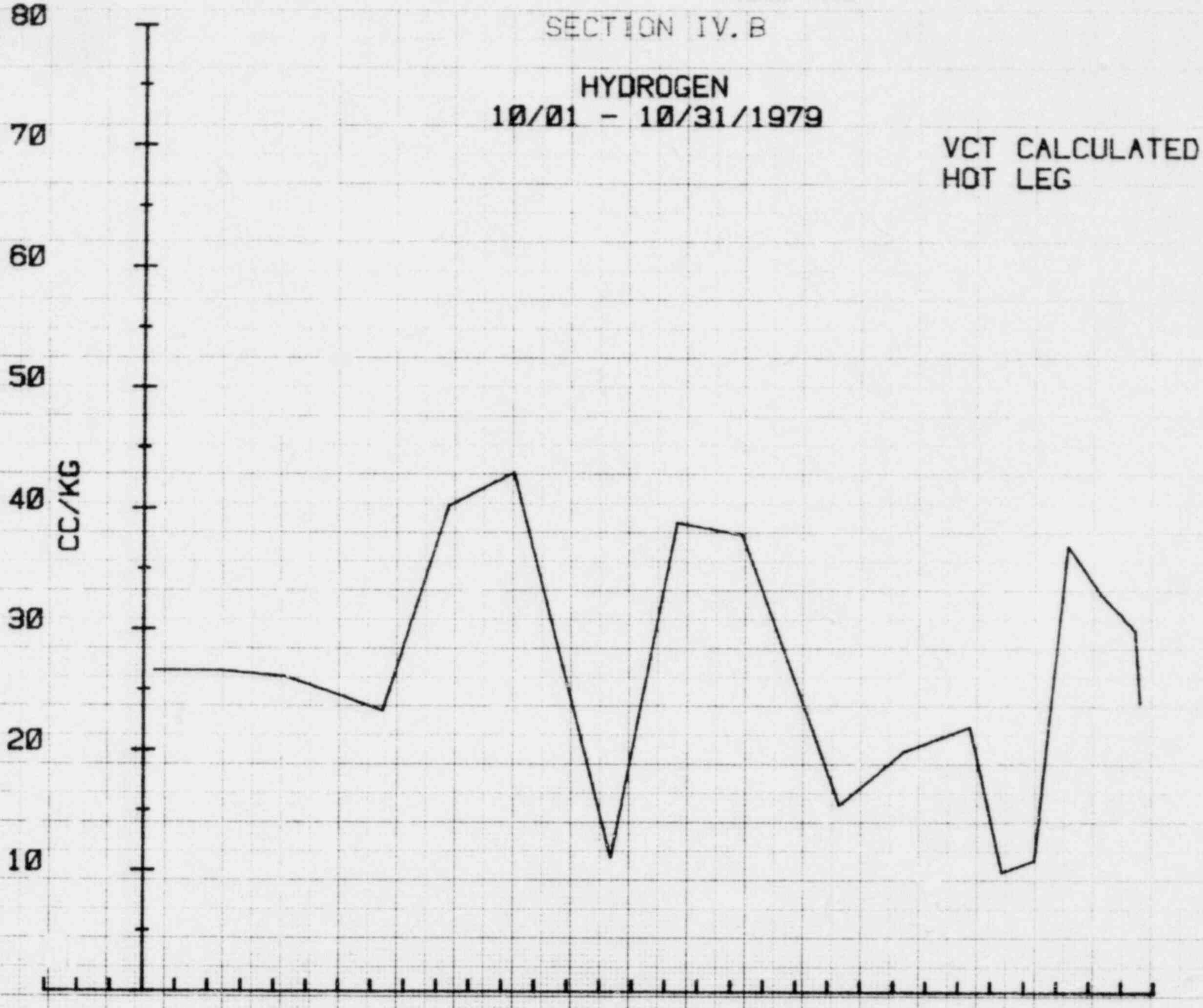
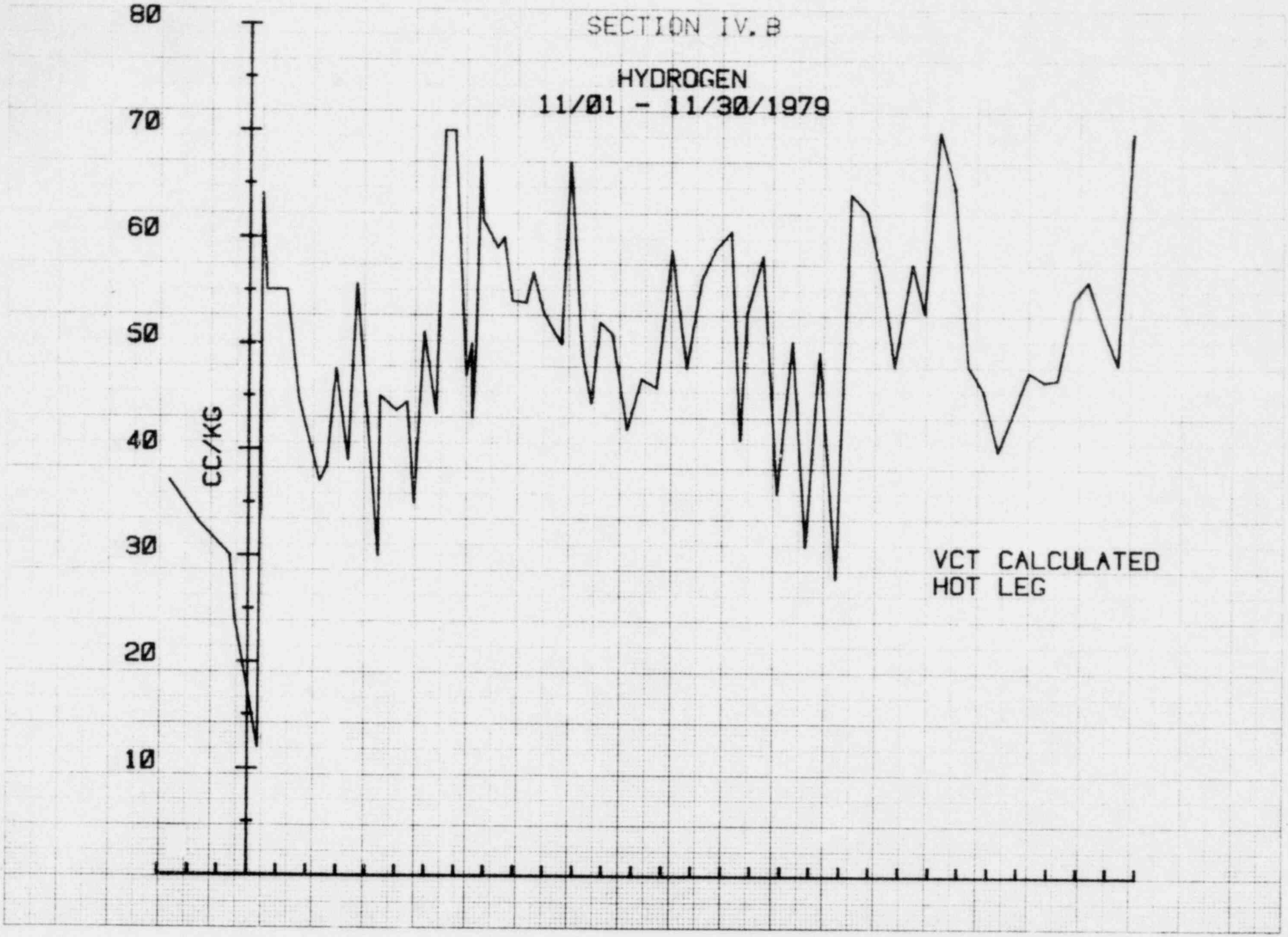

SECTION IV.B
HYDROGEN
10/01 - 10/31/1979
VCT CALCULATED
HOT LEG
CC/KG
80
70
60
50
40
30
20
10

FIGURE B.36


SECTION IV.B

HYDROGEN
11/01 - 11/30/1979

FIGURE B.37

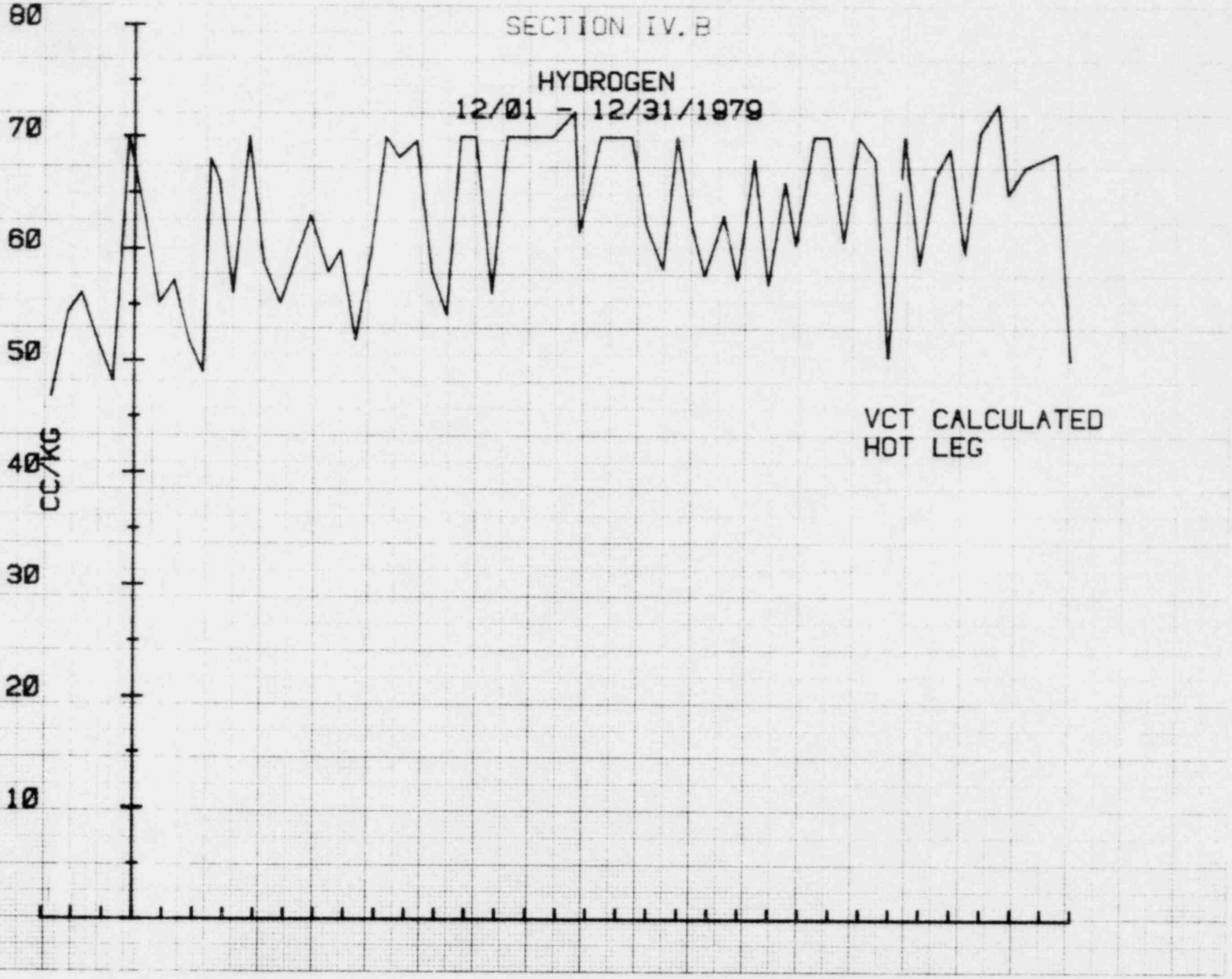

SECTION IV.B
HYDROGEN
12/01 - 12/31/1979
80
70
60
50
40
30
20
10
CC/KG
VCT CALCULATED
HOT LEG

FIGURE B.38

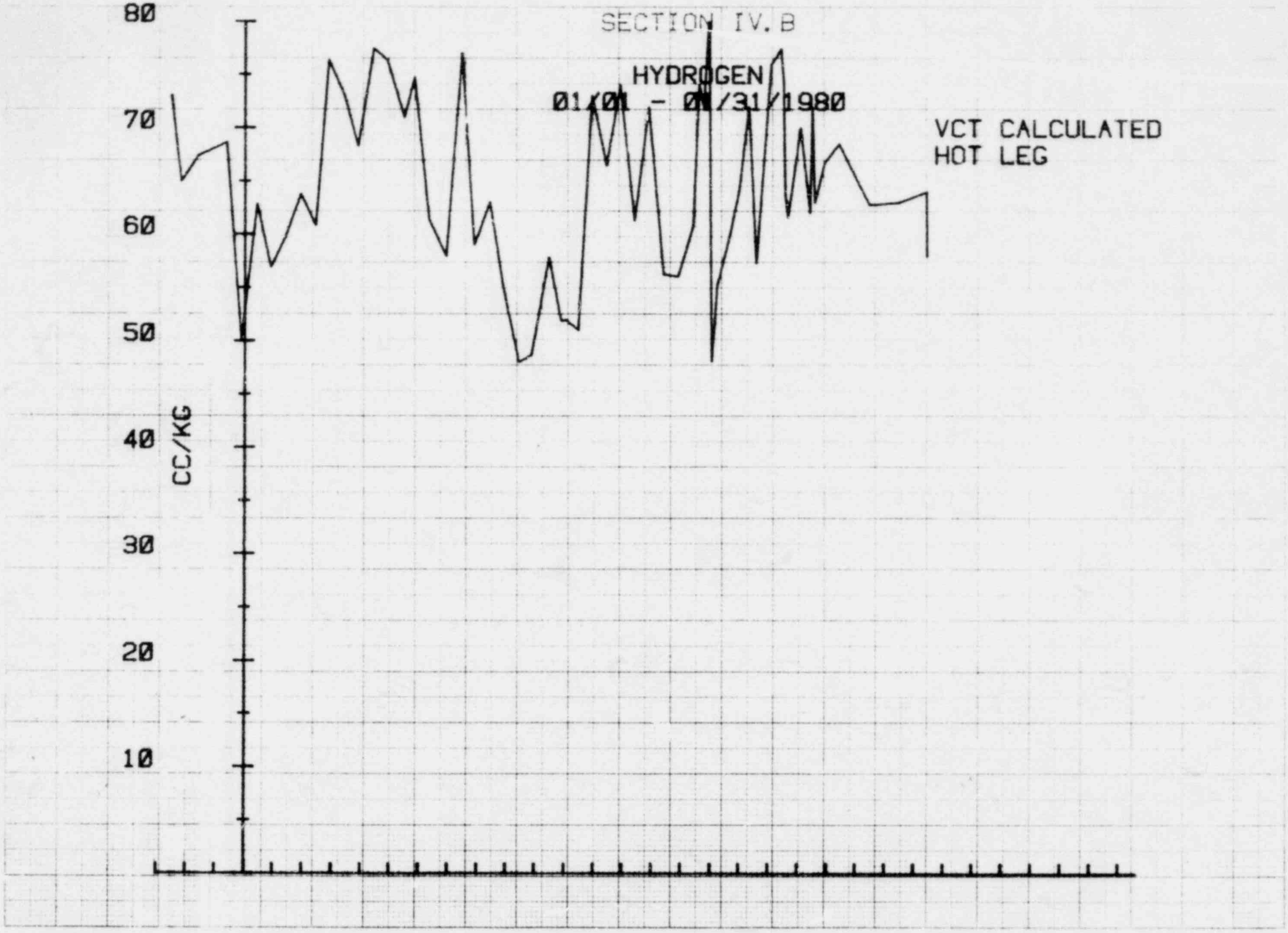

SECTION IV.B
HYDROGEN
01/01 - 01/31/1980
VCT CALCULATED
HOT LEG
CC/KG
80
70
60
50
40
30
20
10

FIGURE B.39

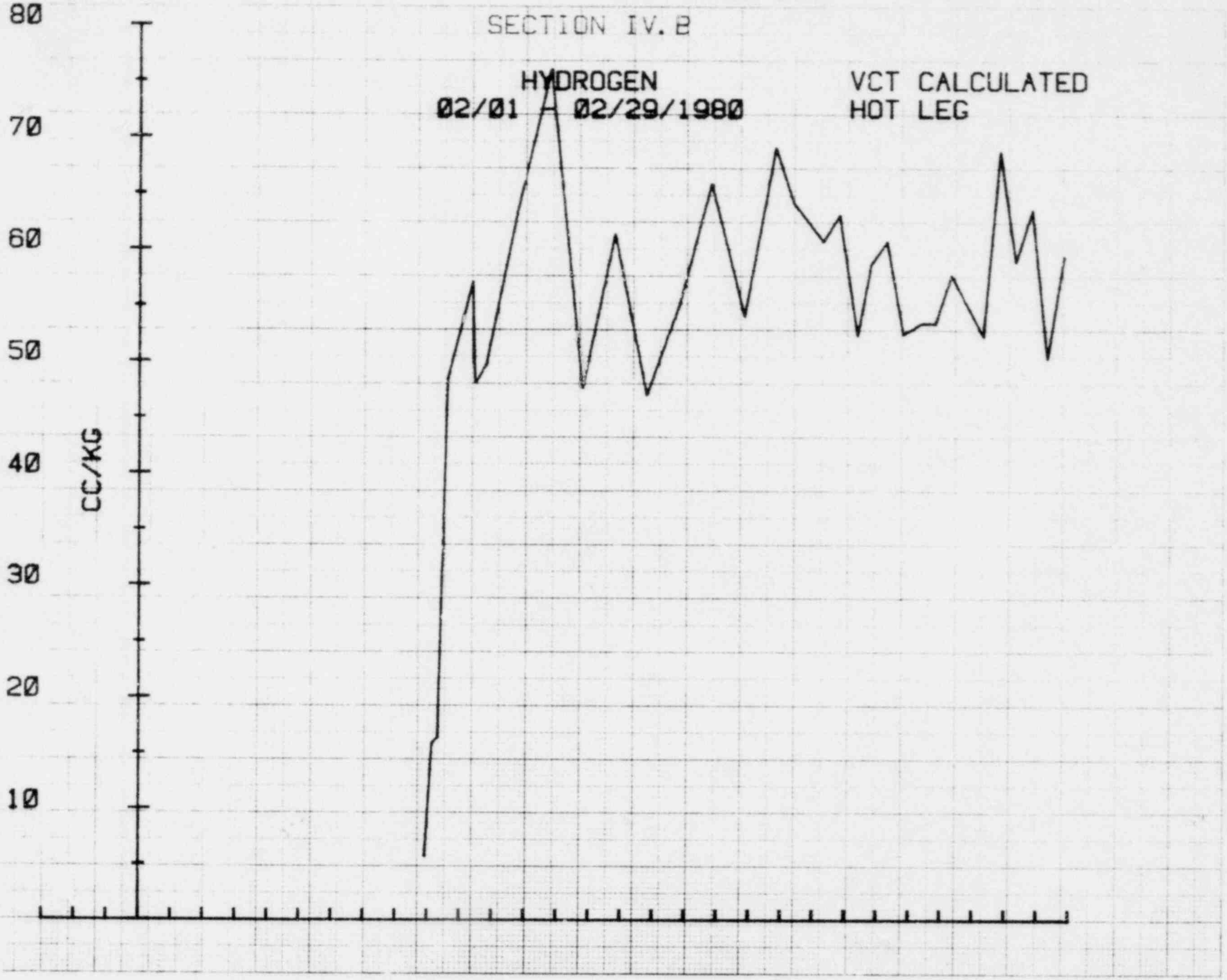
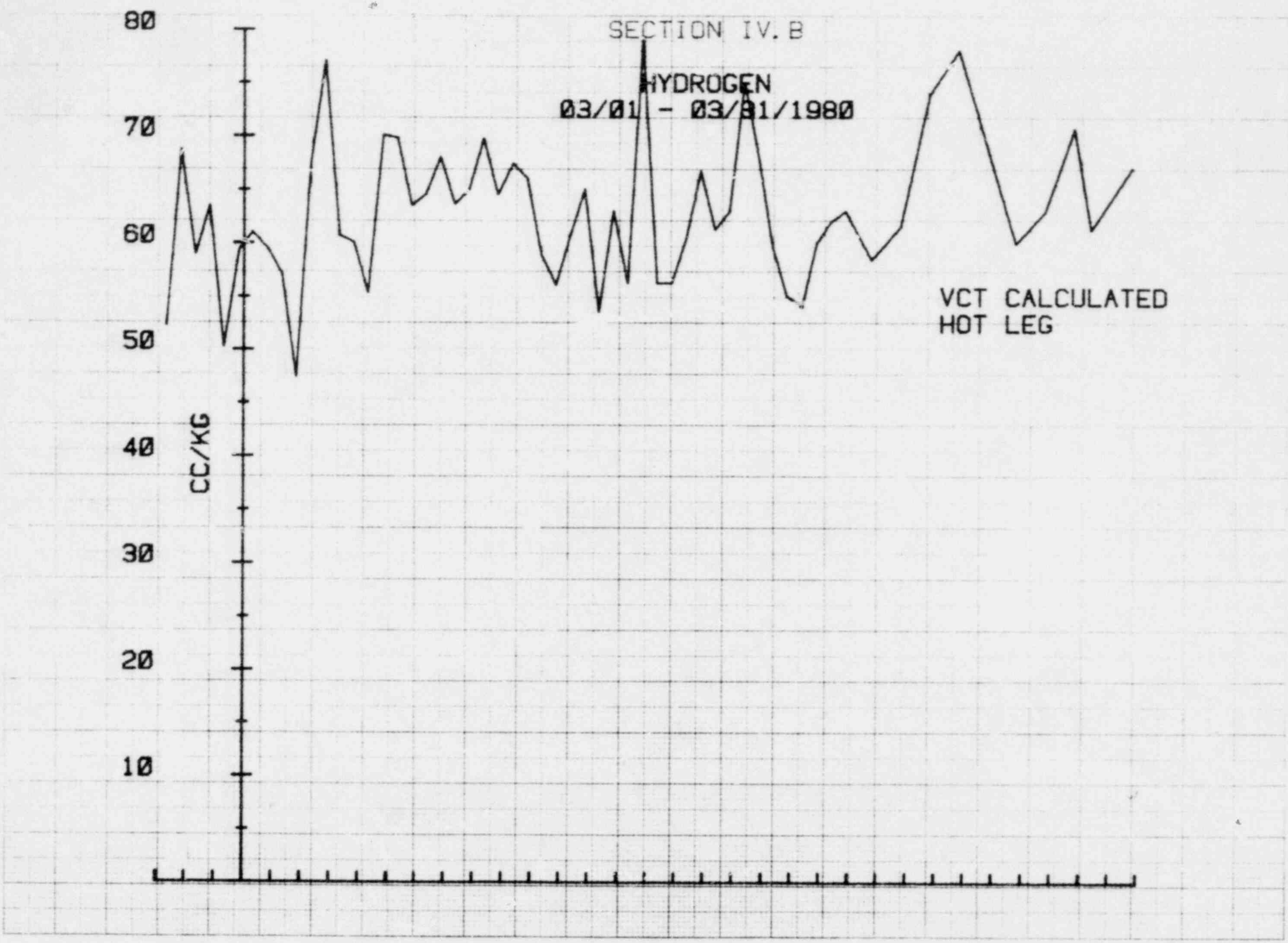

SECTION IV.B
HYDROGEN
02/01 - 02/29/1980
VCT CALCULATED
HOT LEG
CC/KG
80
70
60
50
40
30
20
10

FIGURE B.40


SECTION IV.B
HYDROGEN
03/01 - 03/31/1980
VCT CALCULATED
HOT LEG
CC/KG
80
70
60
50
40
30
20
10

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 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

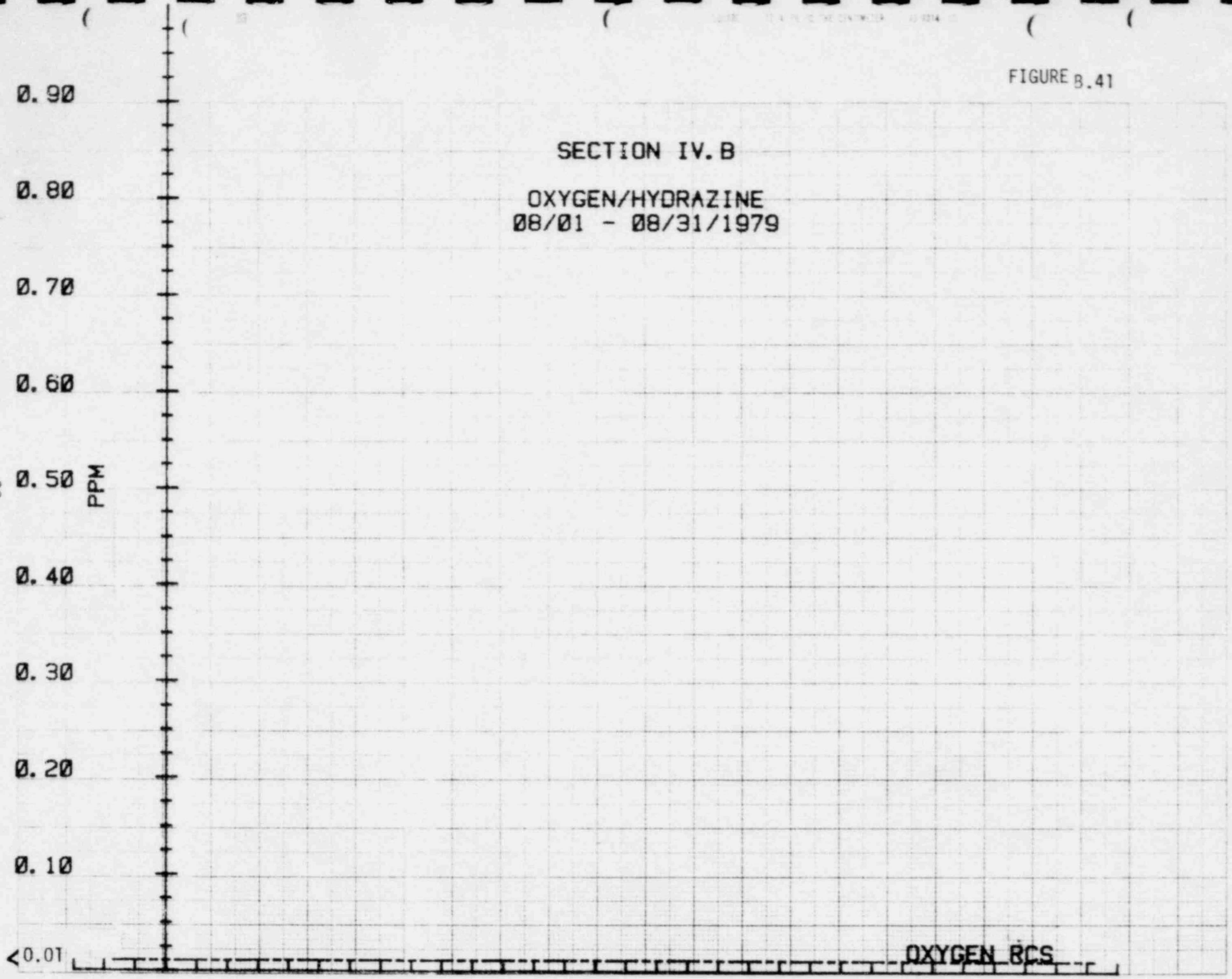

SECTION IV.B
OXYGEN/HYDRAZINE
08/01 - 08/31/1979
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
<0.01
PPM
OXYGEN RCS

FIGURE B.42

SECTION IV.B

OXYGEN/HYDRAZINE
09/01 - 09/30/1979

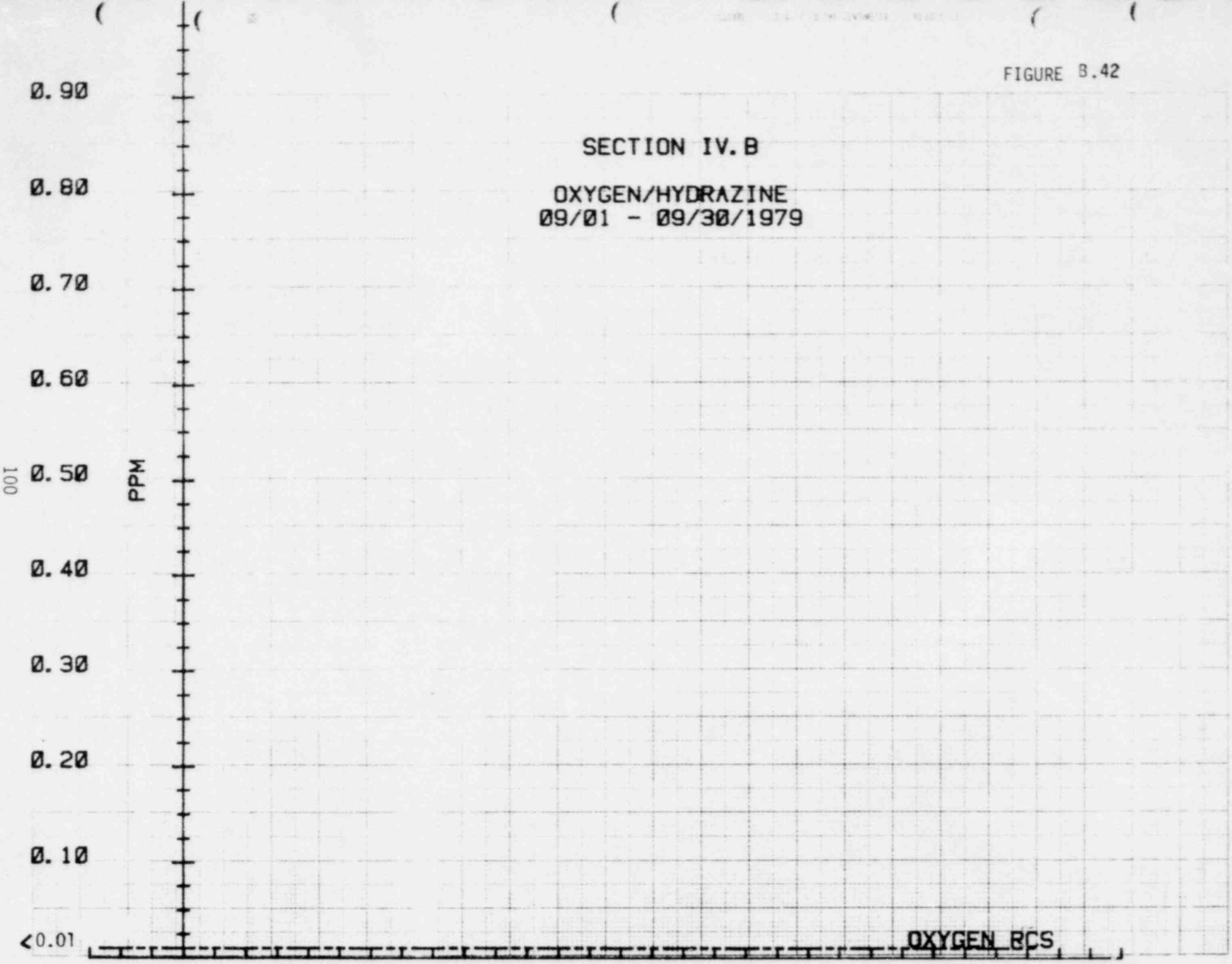
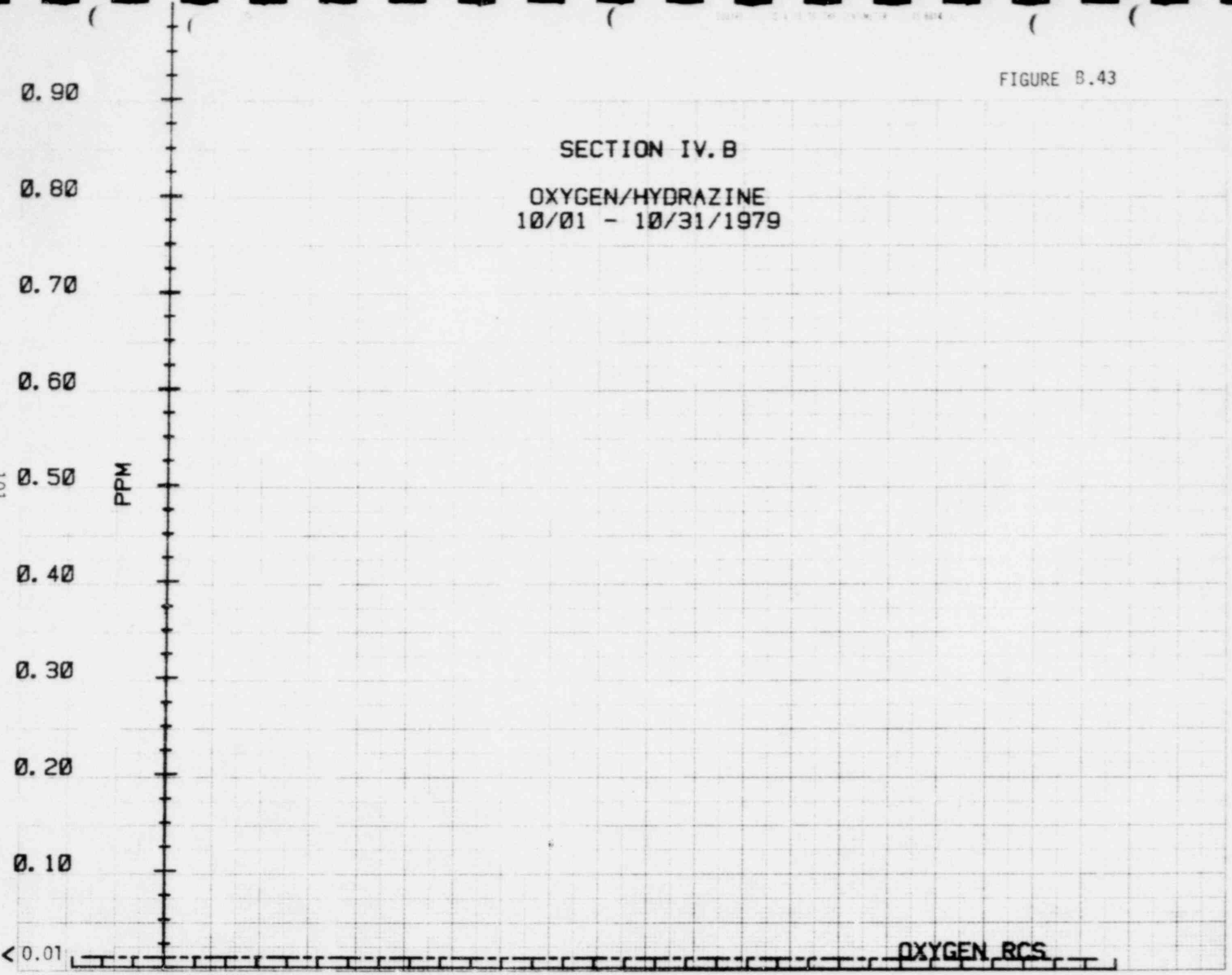


FIGURE B.43



SECTION IV.B

OXYGEN/HYDRAZINE
10/01 - 10/31/1979

FIGURE B.44

SECTION IV.B

OXYGEN/HYDRAZINE
11/01 - 11/30/1979

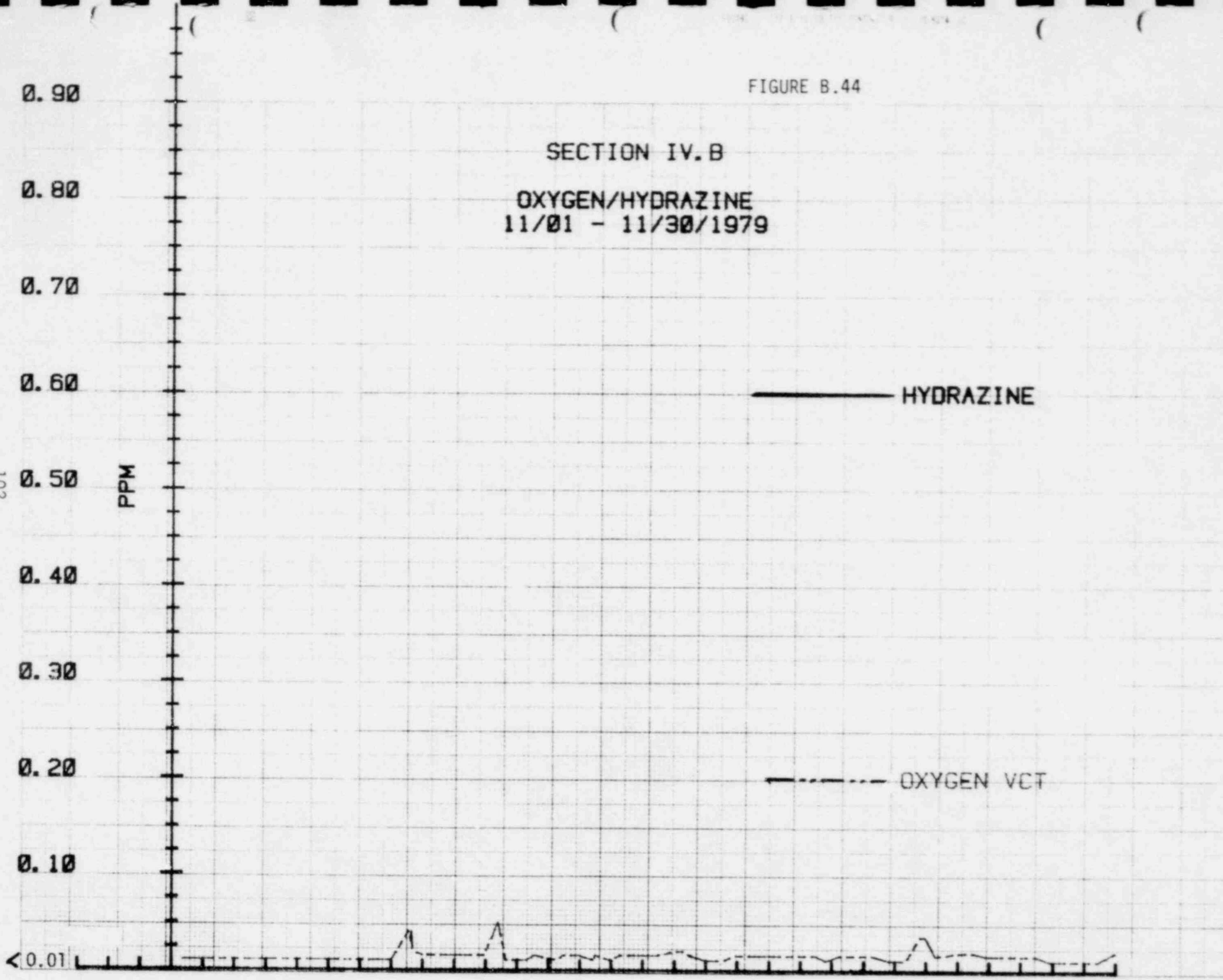
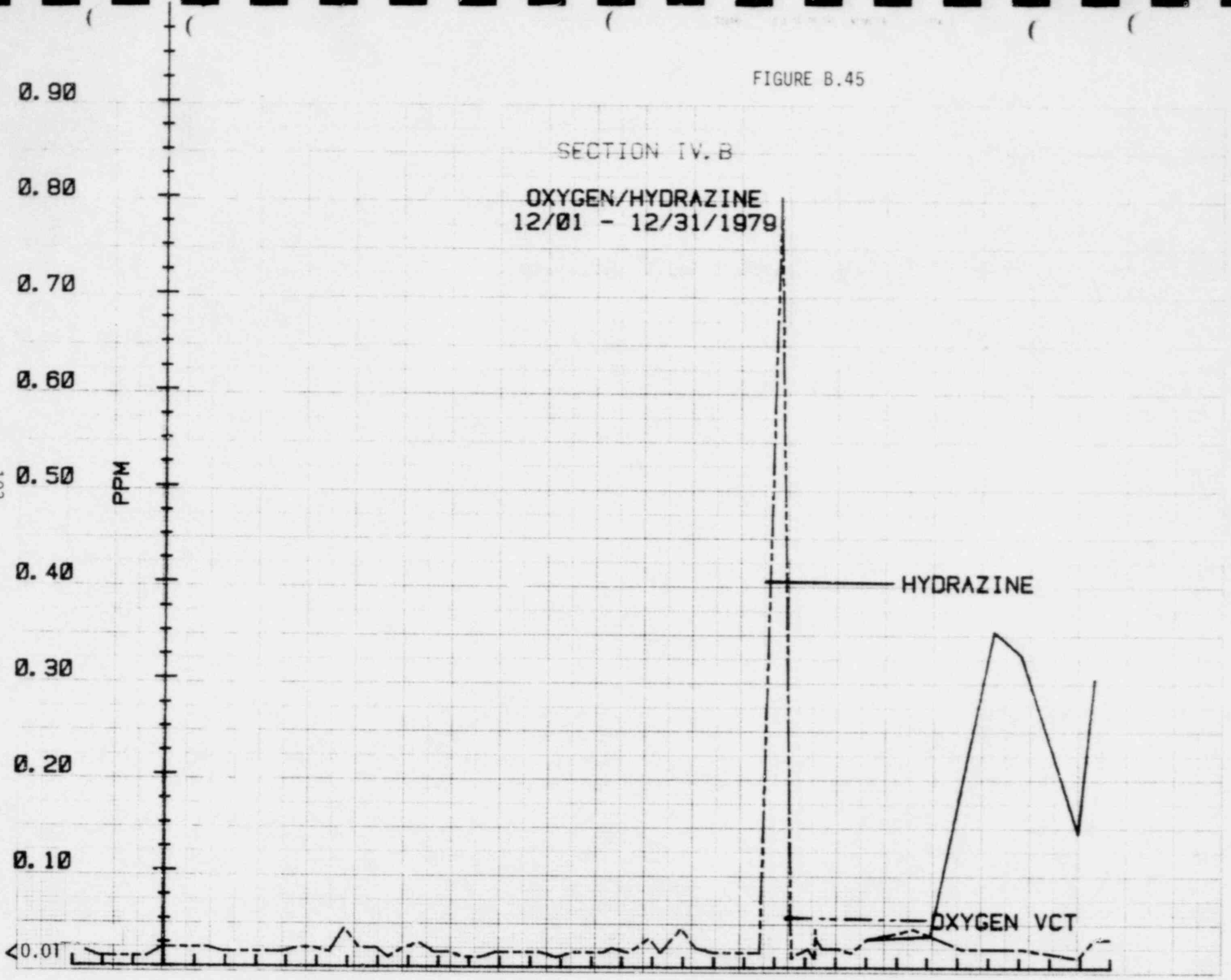


FIGURE B.45

SECTION IV.B



OXYGEN/HYDRAZINE
12/01 - 12/31/1979

FIGURE B.46

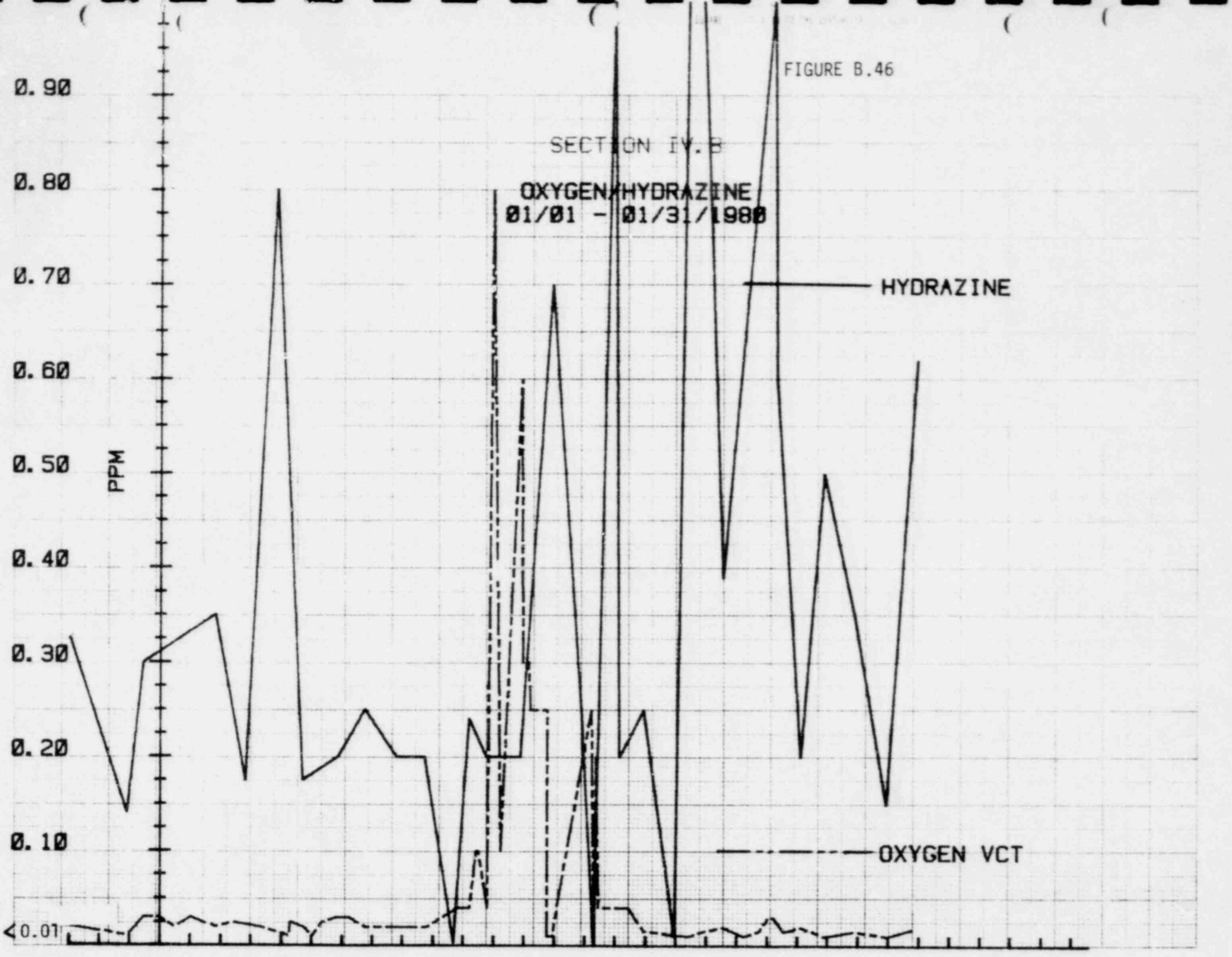

SECTION IV.B
OXYGEN/HYDRAZINE
01/01 - 01/31/1980
HYDRAZINE
OXYGEN VCT
PPM
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
<0.01

FIGURE B.47

SECTION IV.B

OXYGEN/HYDRAZINE
02/01 - 02/29/1980

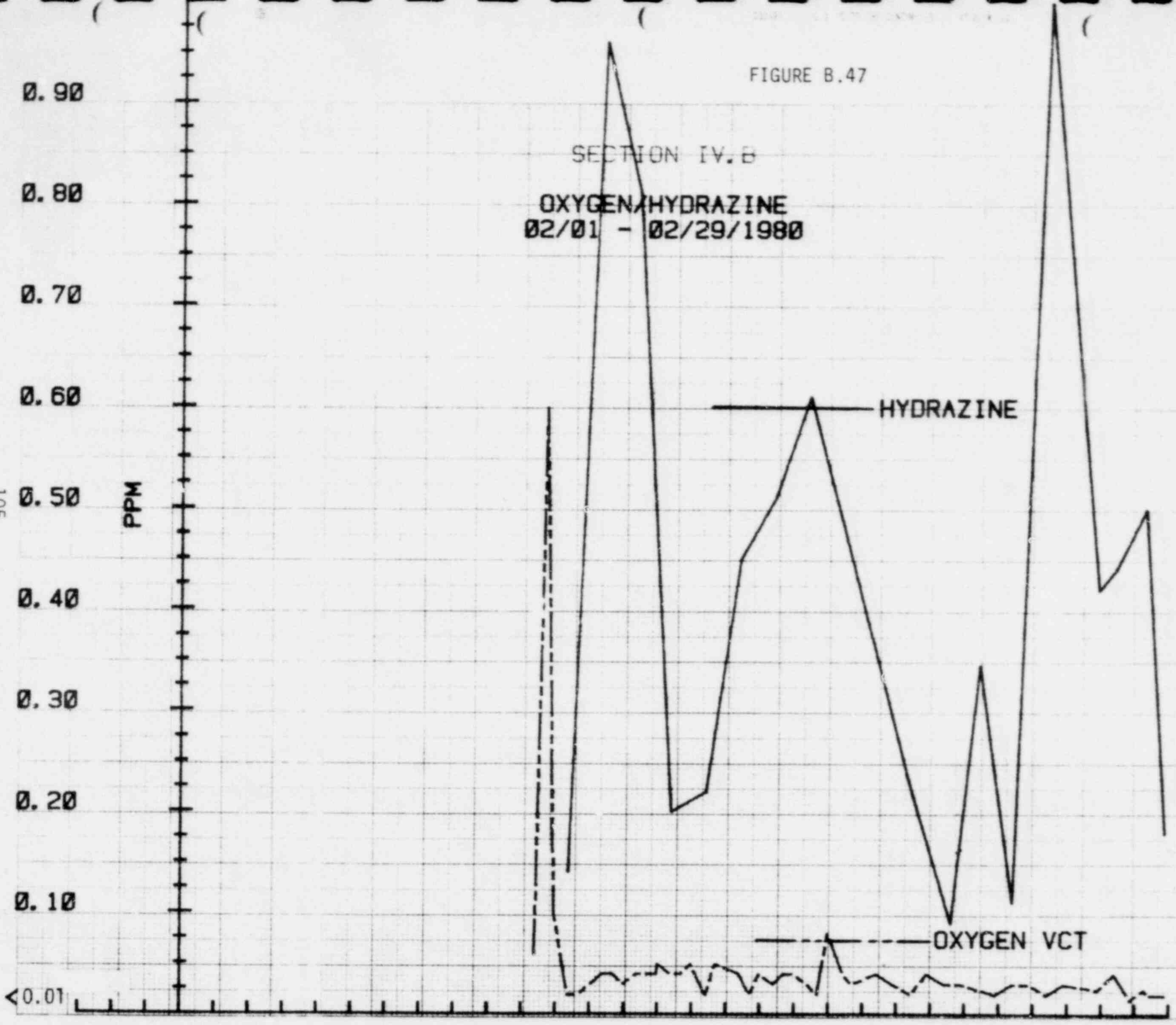
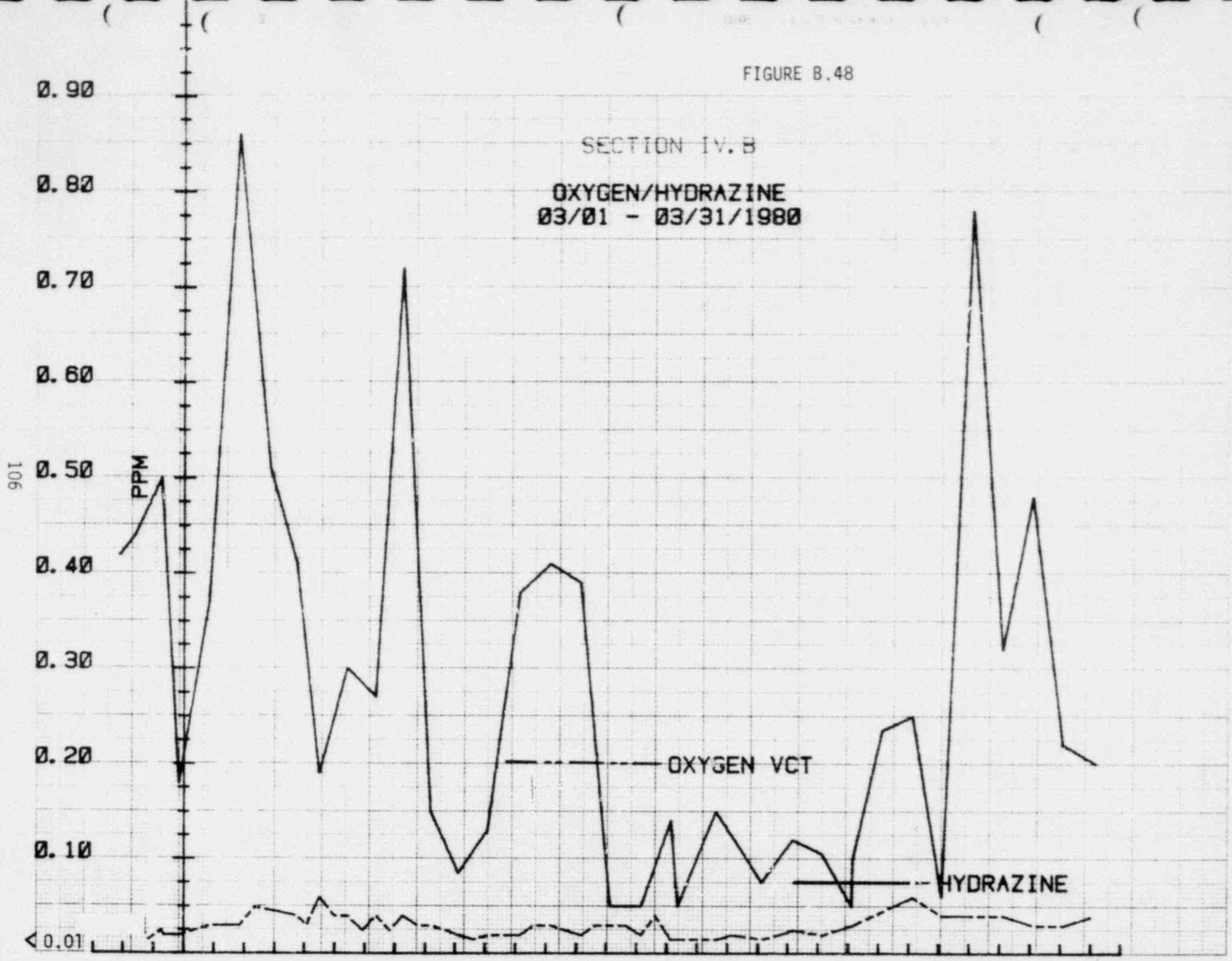


FIGURE B.48


SECTION IV.B

OXYGEN/HYDRAZINE
03/01 - 03/31/1980

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

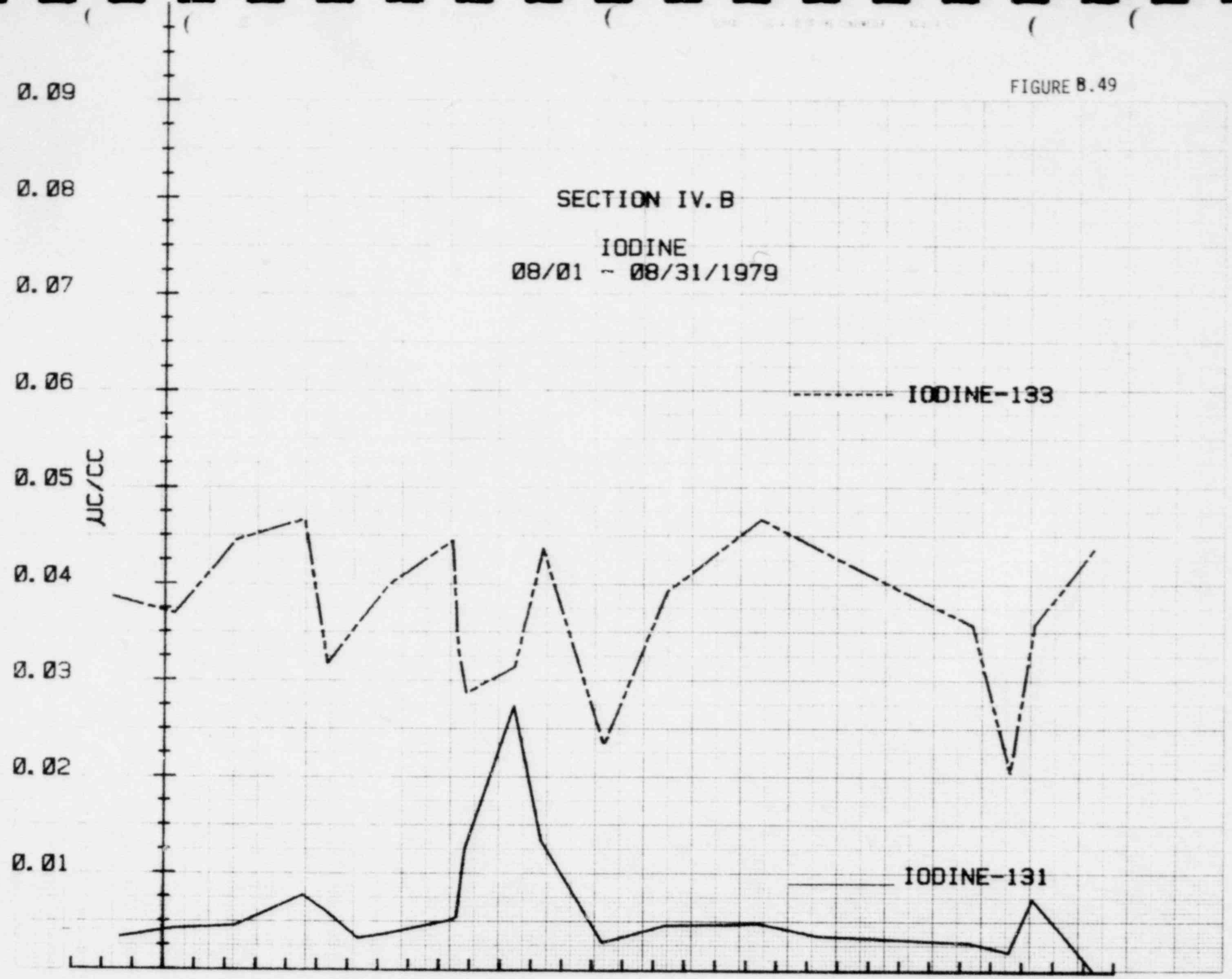

SECTION IV.B
IODINE
08/01 - 08/31/1979
IODINE-133
IODINE-131
μC/CC
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01

FIGURE B.50

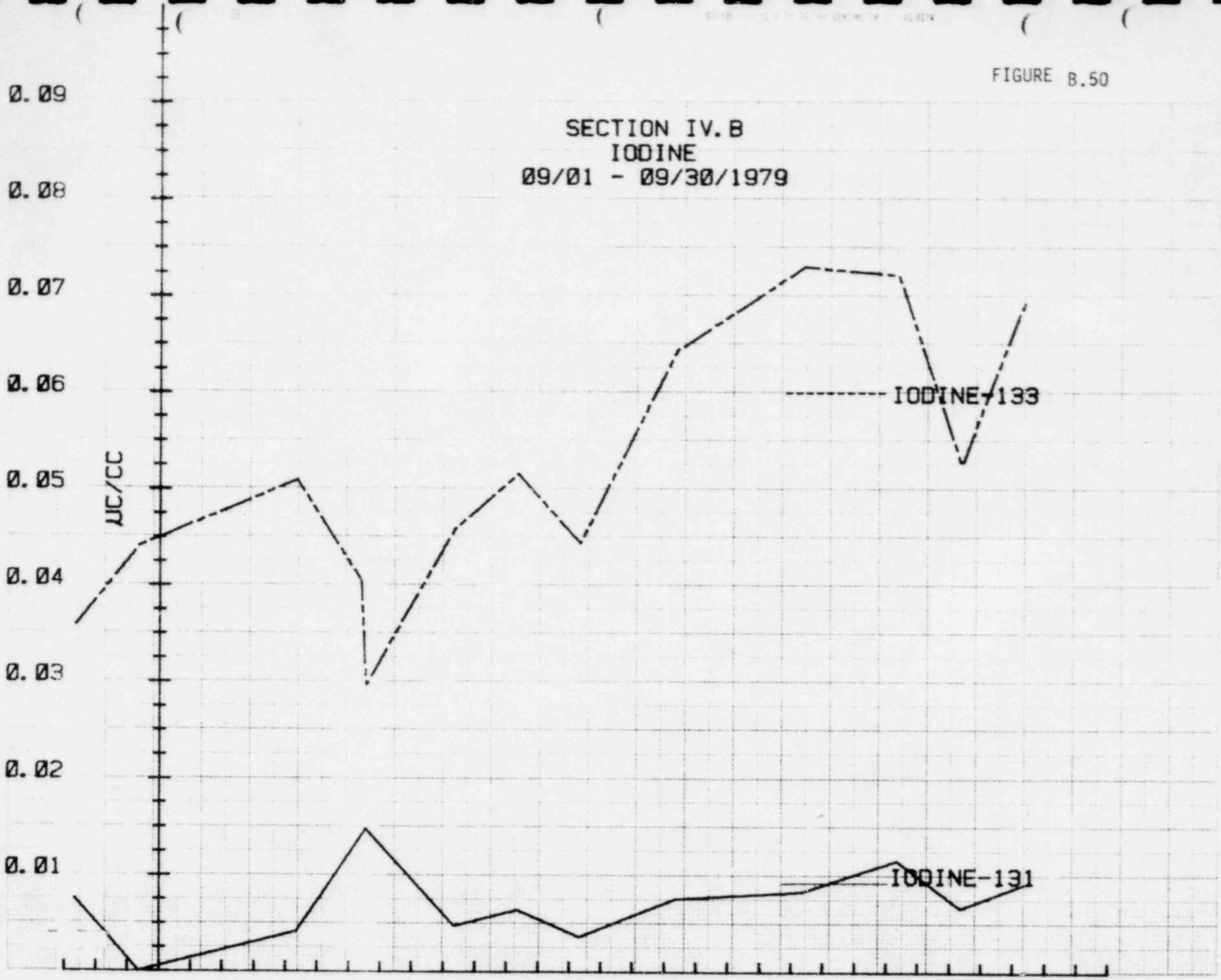

SECTION IV.B
IODINE
09/01 - 09/30/1979
µC/CC
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
IODINE-133
IODINE-131

FIGURE B.51

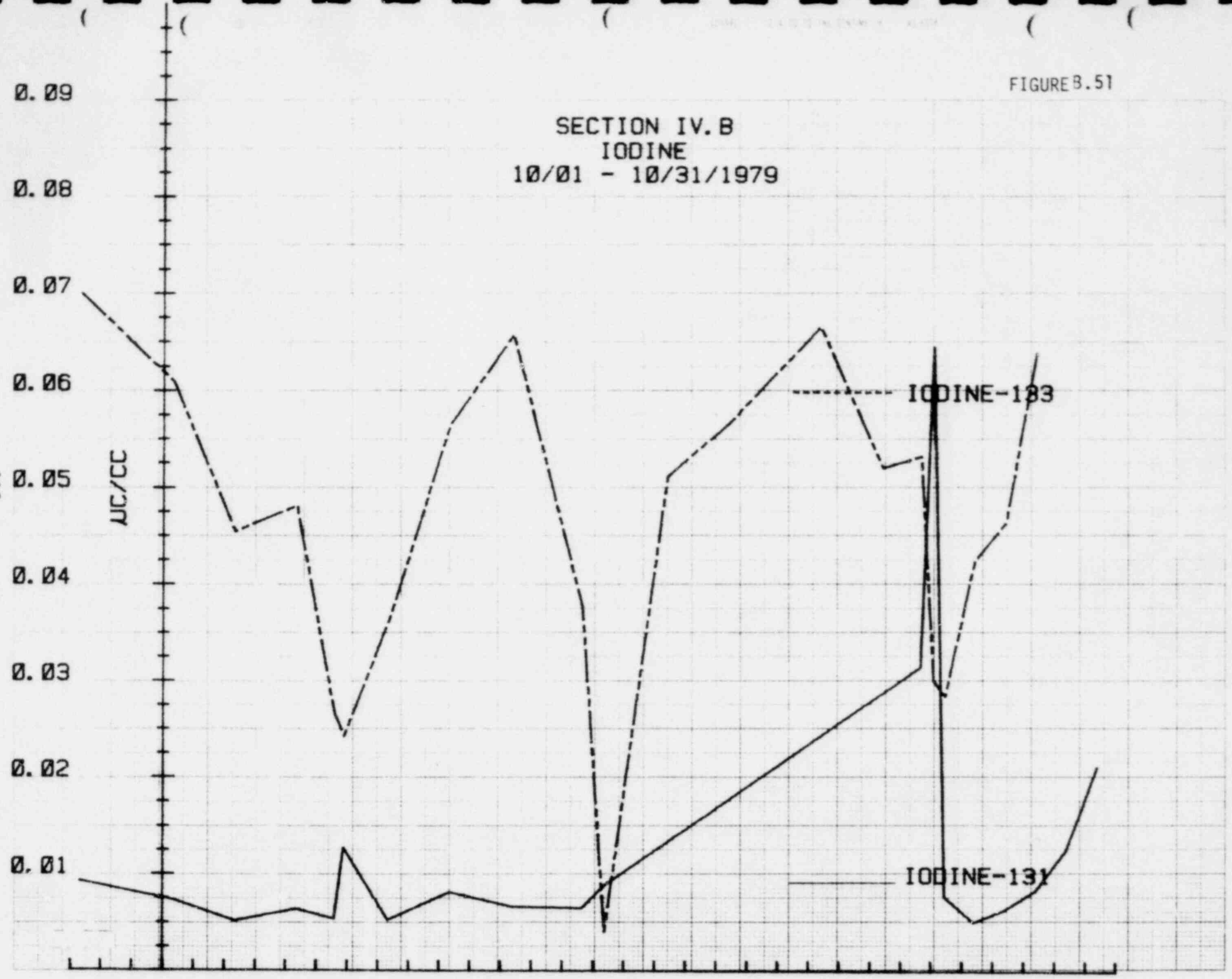

SECTION IV.B
IODINE
10/01 - 10/31/1979

FIGURE B.52

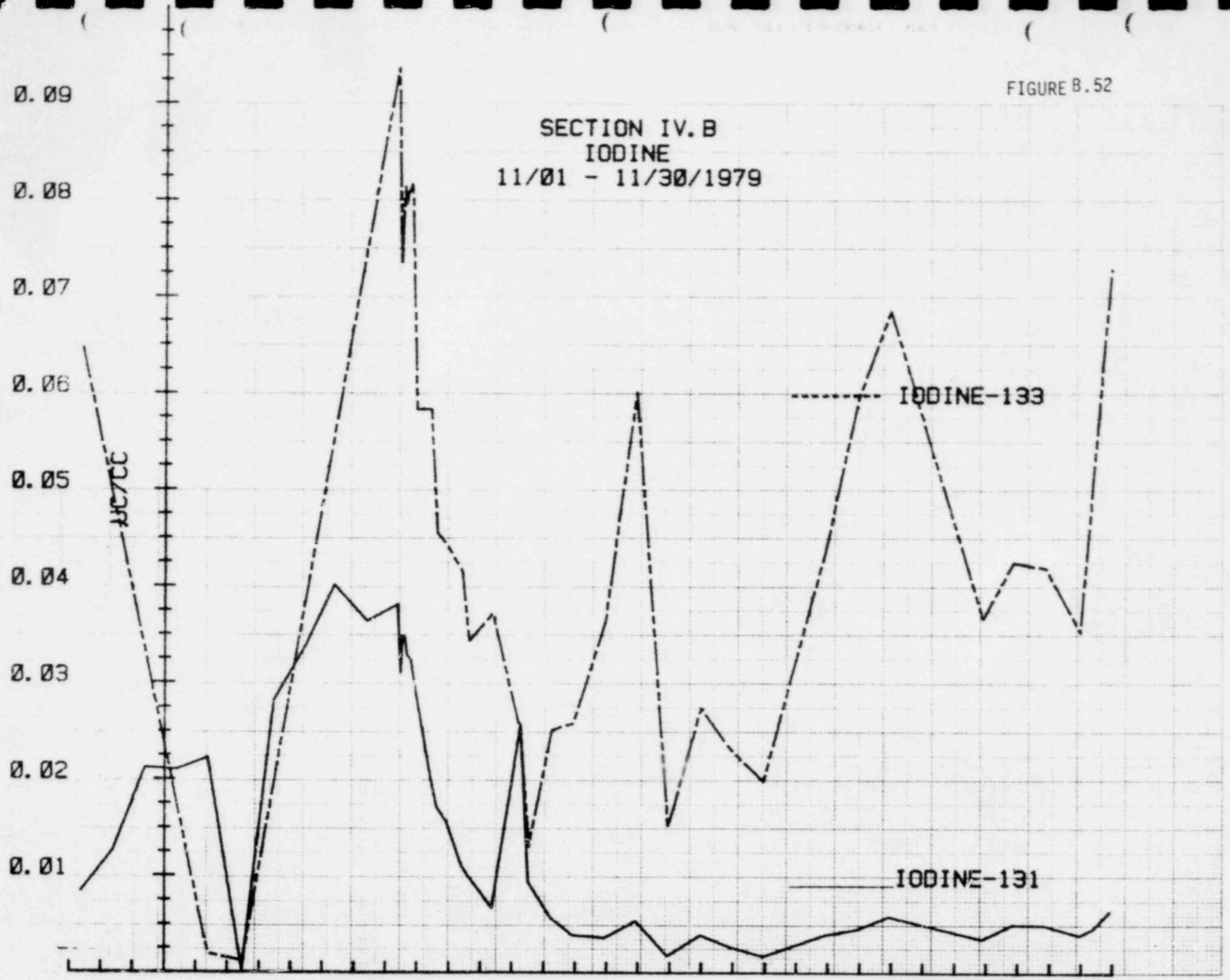

SECTION IV.B
IODINE
11/01 - 11/30/1979
UC/CC
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
IODINE-133
IODINE-131

FIGURE B.53

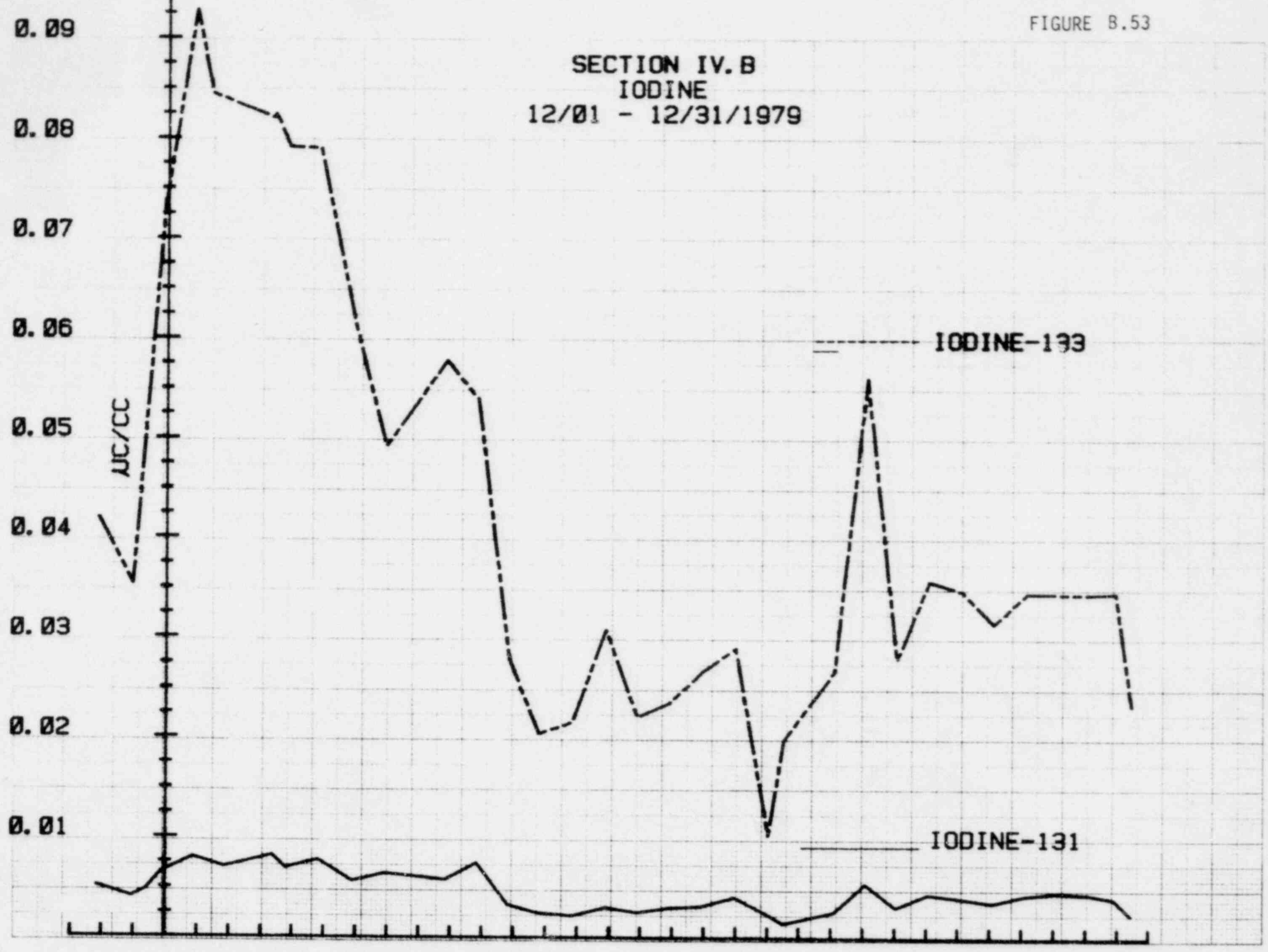

SECTION IV.B
IODINE
12/01 - 12/31/1979
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
μC/CC
IODINE-133
IODINE-131

FIGURE B.54

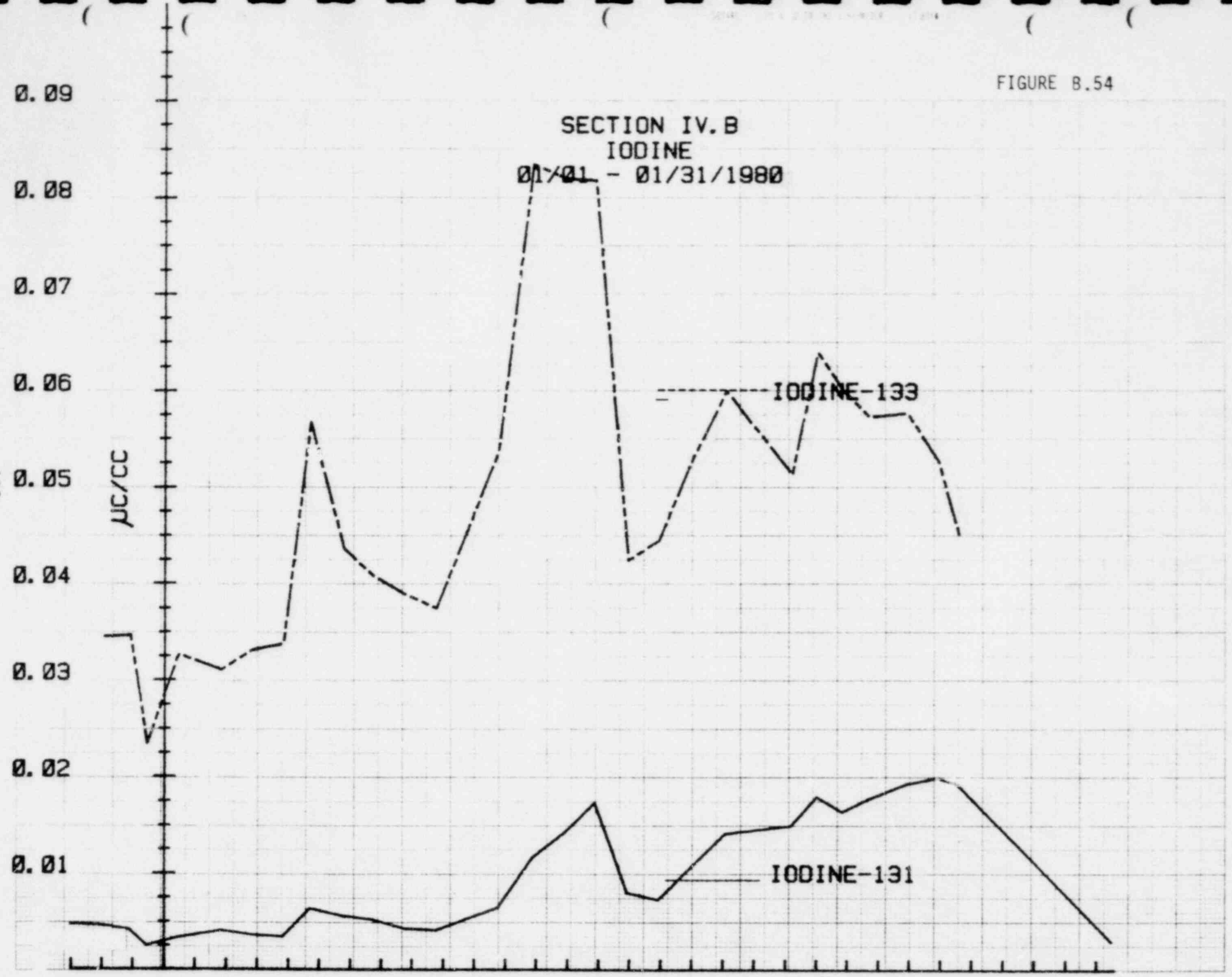
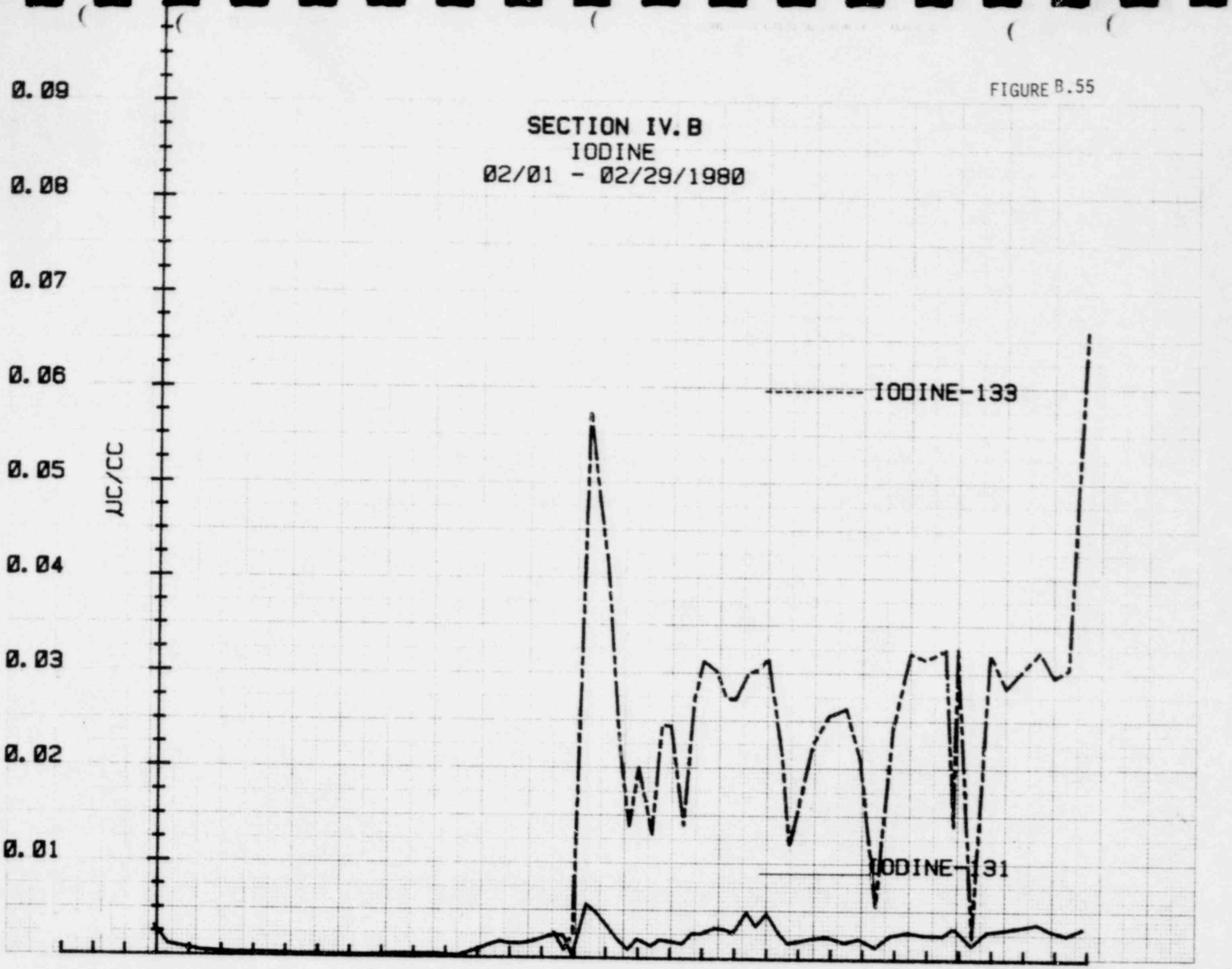

SECTION IV.B
IODINE
01/01 - 01/31/1980
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
µC/CC
IODINE-133
IODINE-131

FIGURE B.55



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

FIGURE B.56

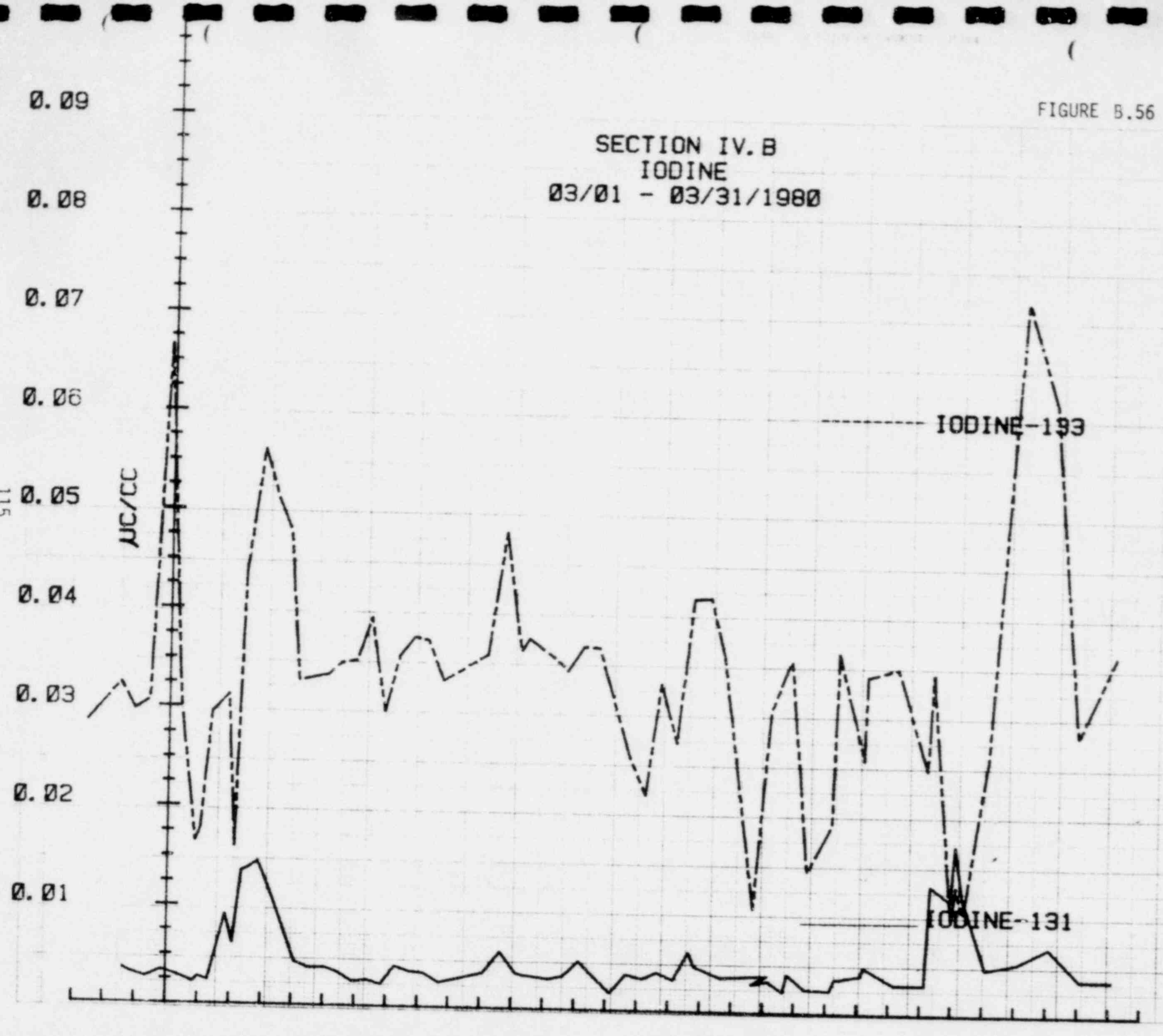
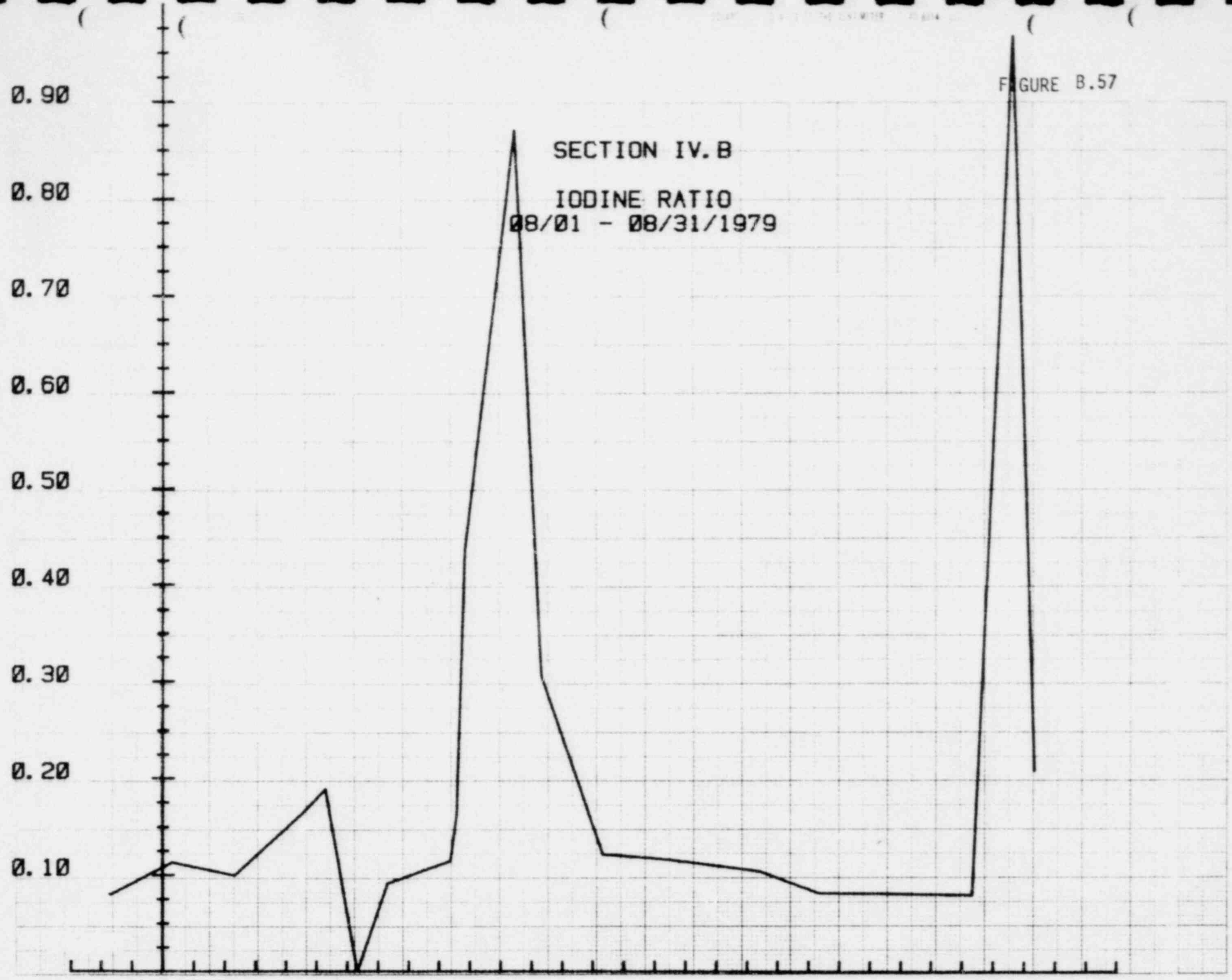

SECTION IV.B
IODINE
03/01 - 03/31/1980
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
µC/CC
IODINE-133
IODINE-131

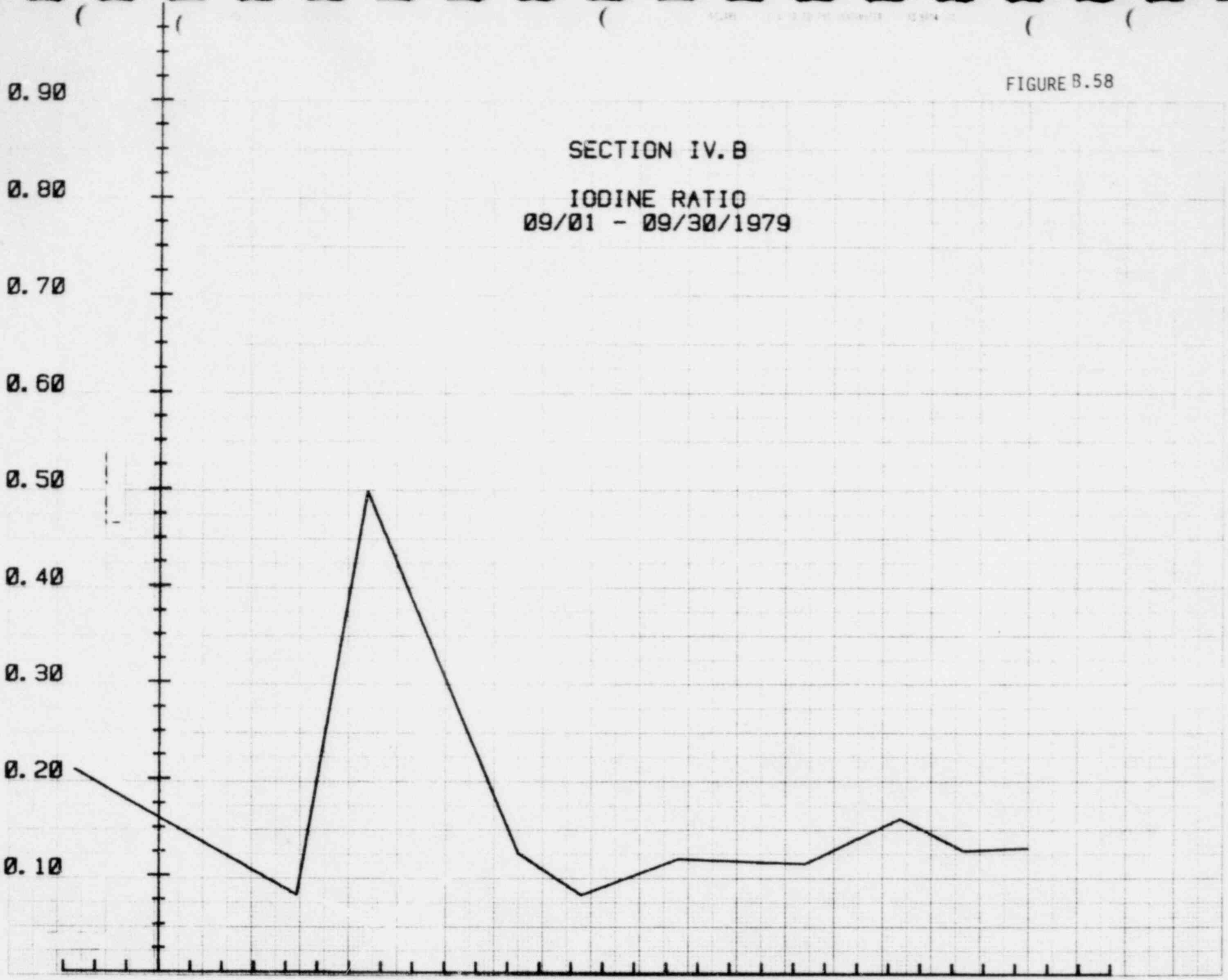
FIGURE B.57


SECTION IV.B

IODINE RATIO

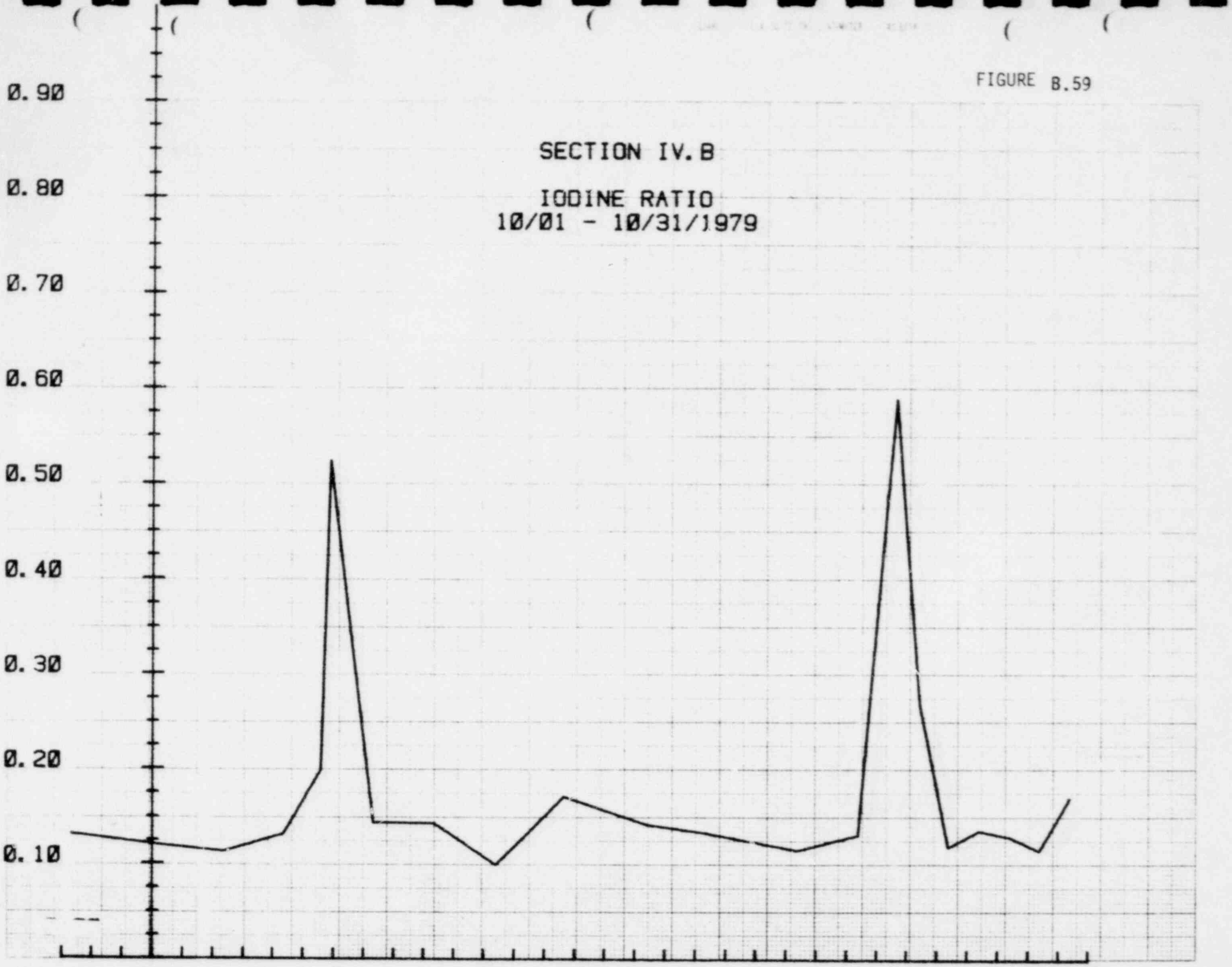
08/01 - 08/31/1979

FIGURE B.58


SECTION IV.B

IODINE RATIO
09/01 - 09/30/1979

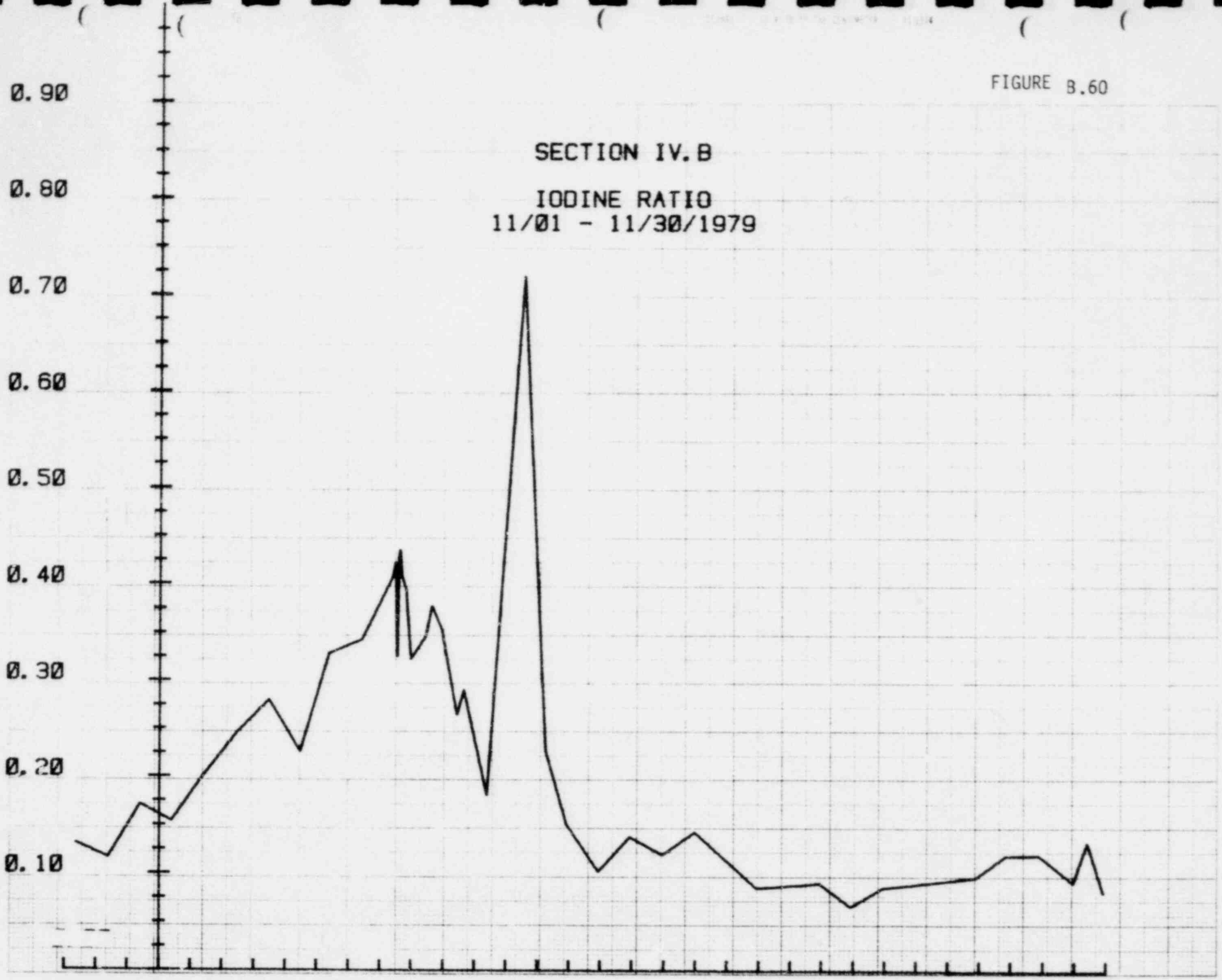
FIGURE B.59



SECTION IV.B

IODINE RATIO
10/01 - 10/31/1979

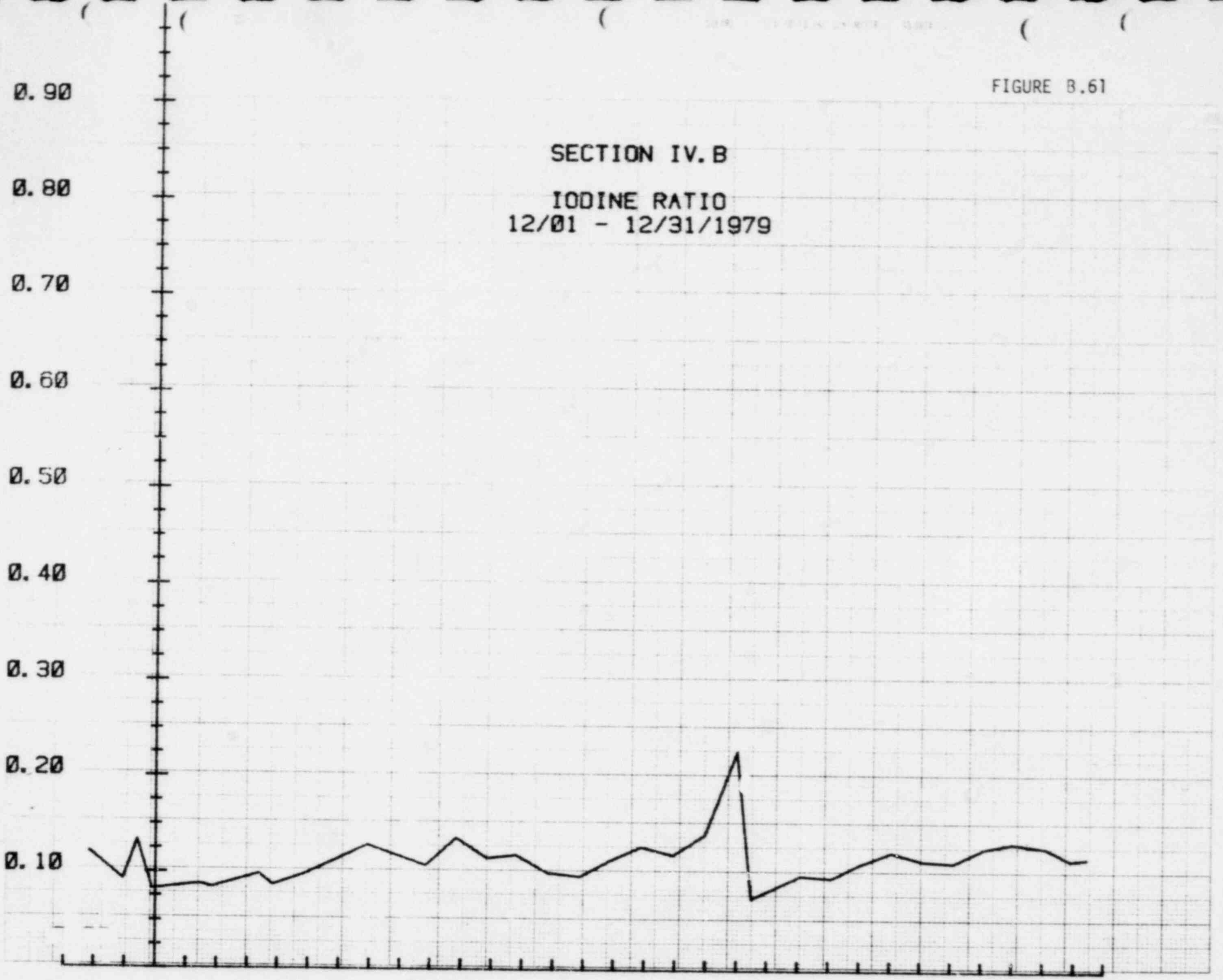
FIGURE B.60



SECTION IV.B

IODINE RATIO
11/01 - 11/30/1979

FIGURE B.61



SECTION IV.B

IODINE RATIO
12/01 - 12/31/1979

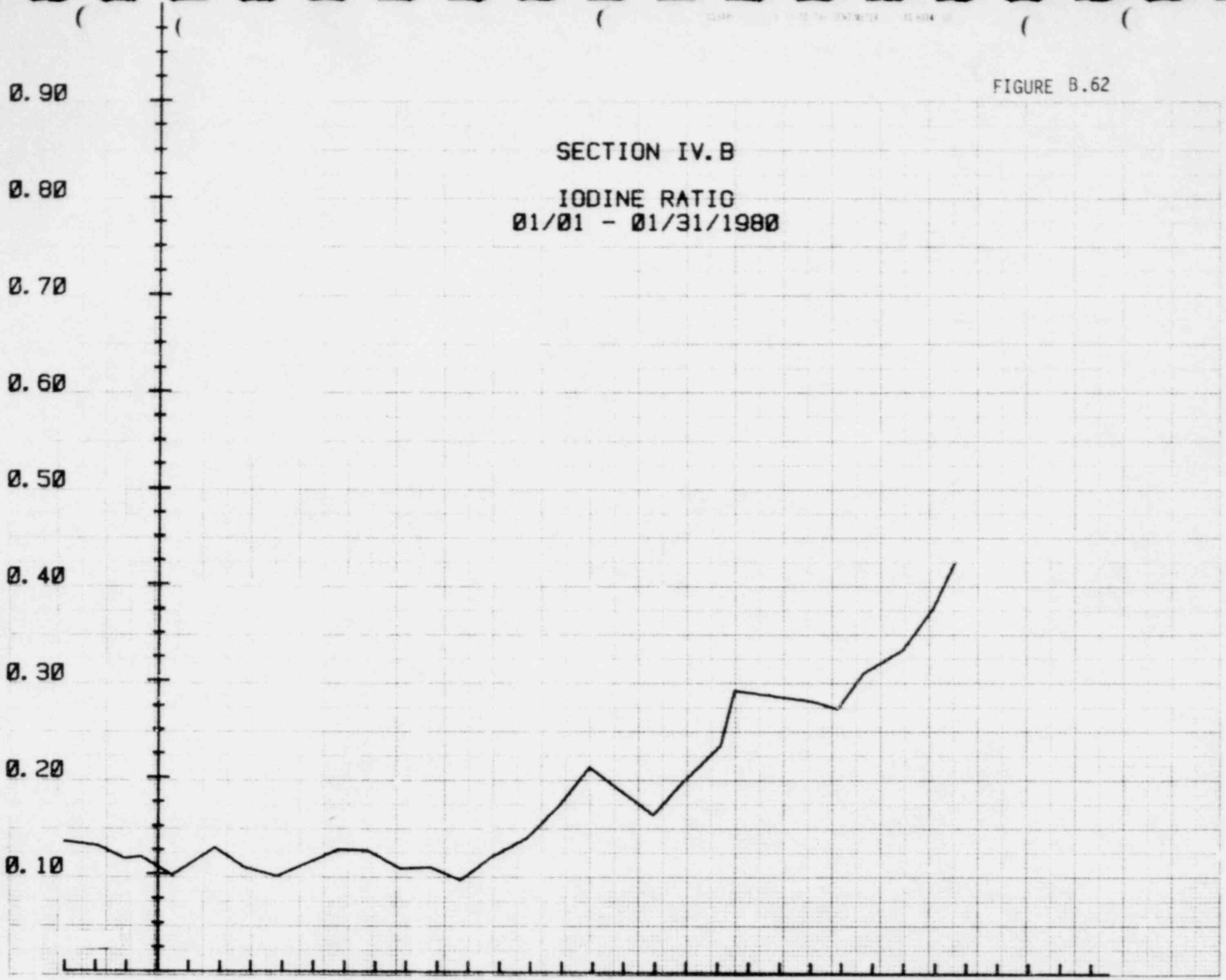
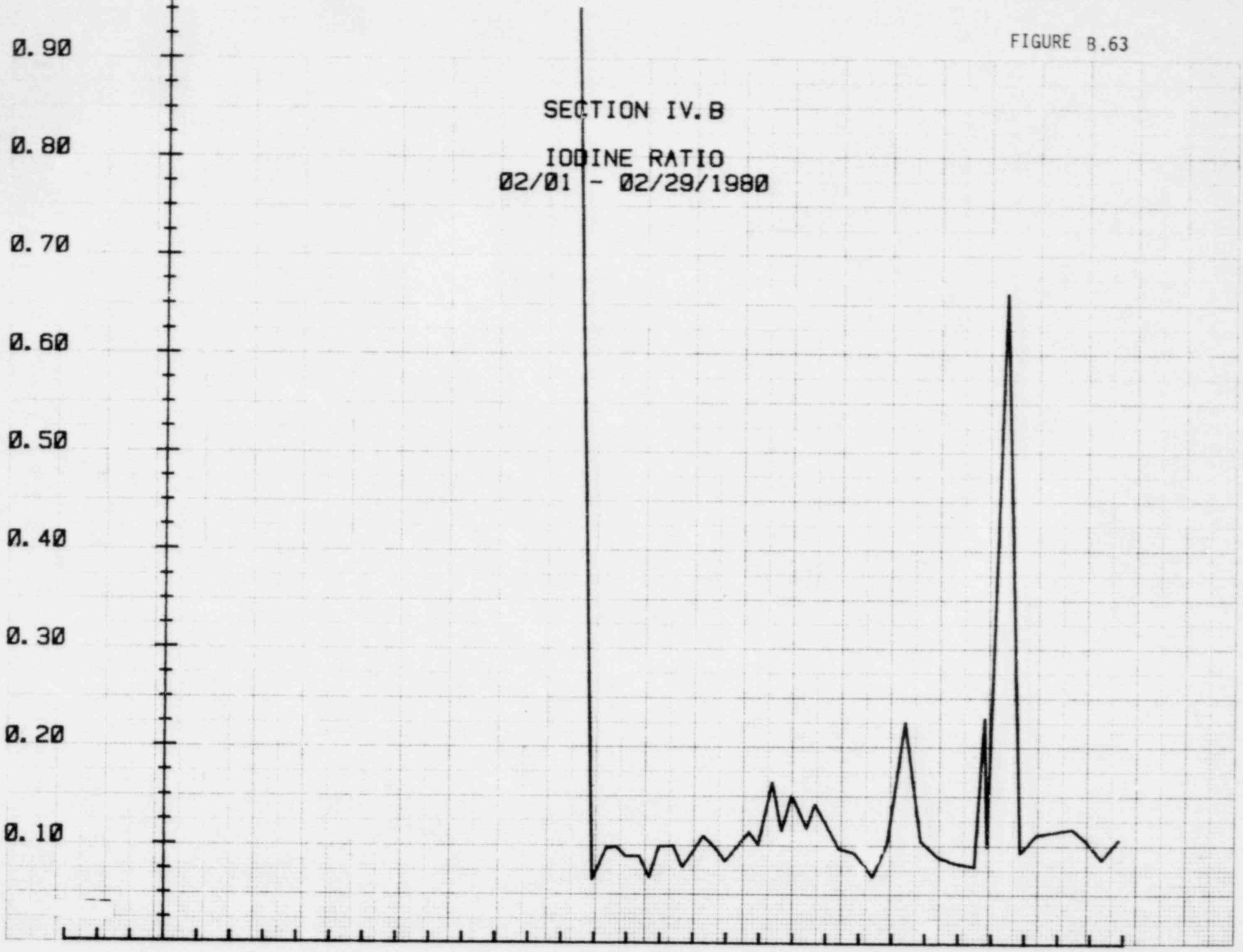


FIGURE B.62

SECTION IV.B

IODINE RATIO
01/01 - 01/31/1980

FIGURE B.63


SECTION IV.B
IODINE RATIO
02/01 - 02/29/1980
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10

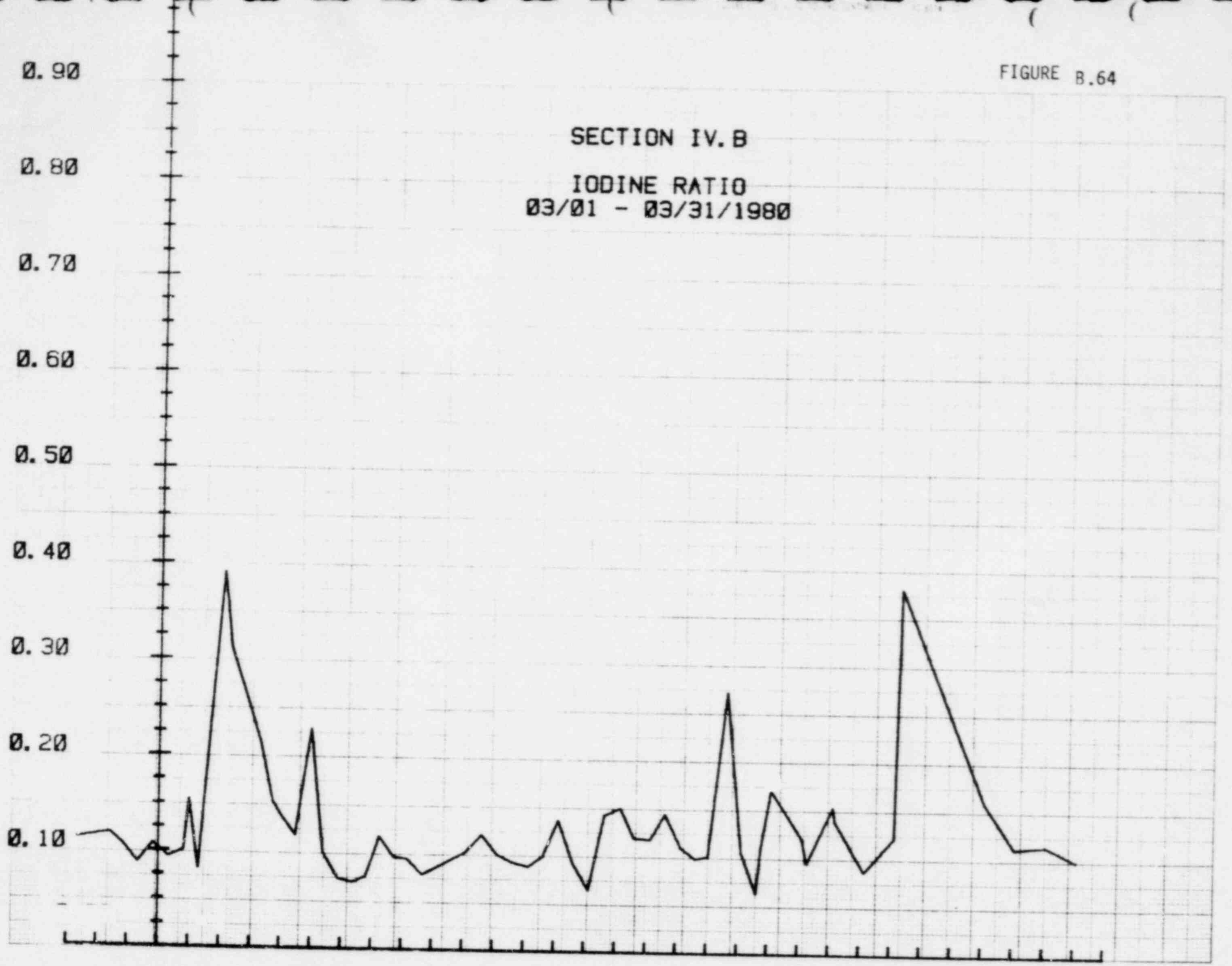


FIGURE B.64

SECTION IV.B

IODINE RATIO
03/01 - 03/31/1980

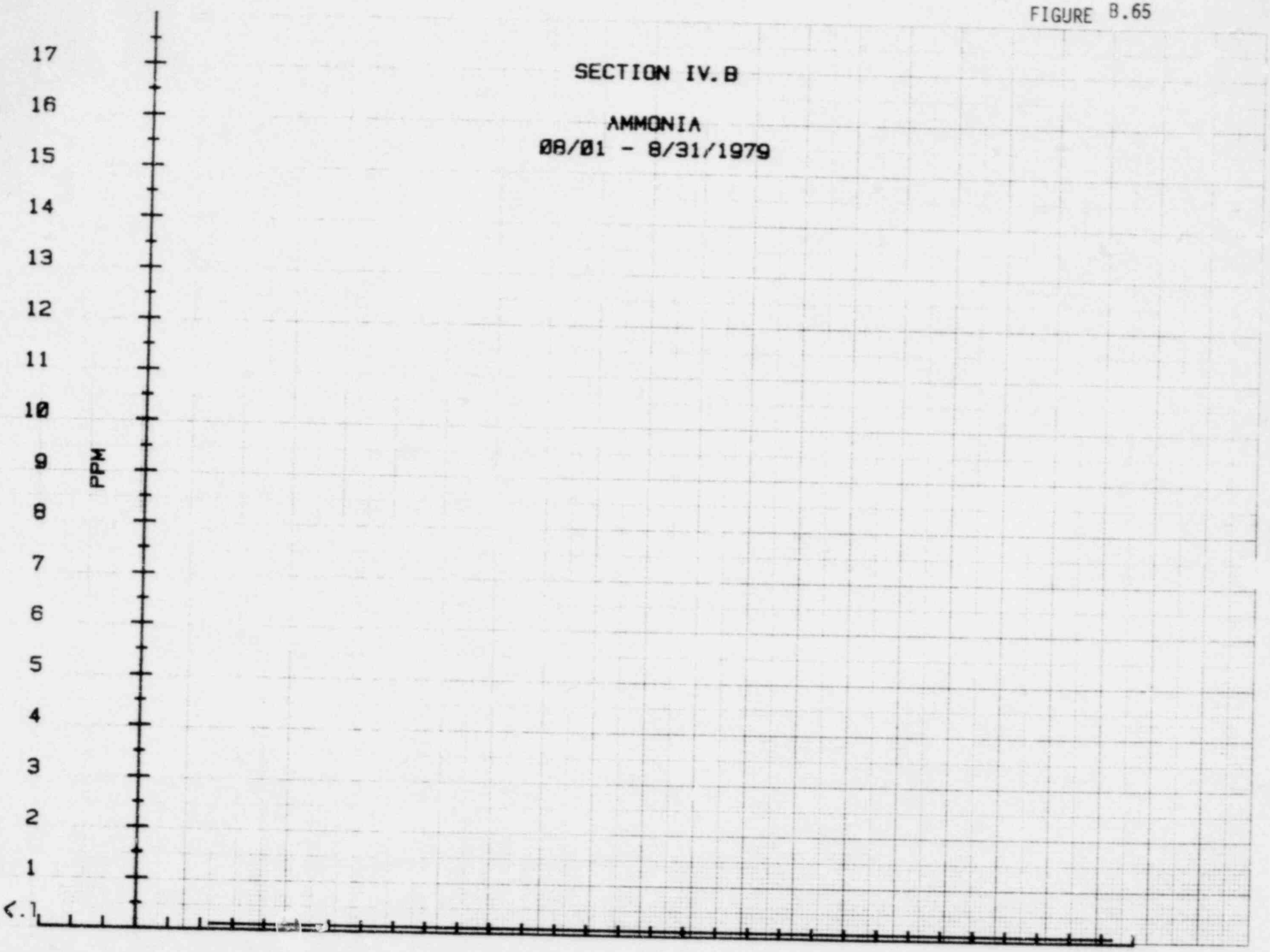
h. Ammonia (Figures B.65-72)

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



SECTION IV.B

AMMONIA
08/01 - 8/31/1979

FIGURE B.66

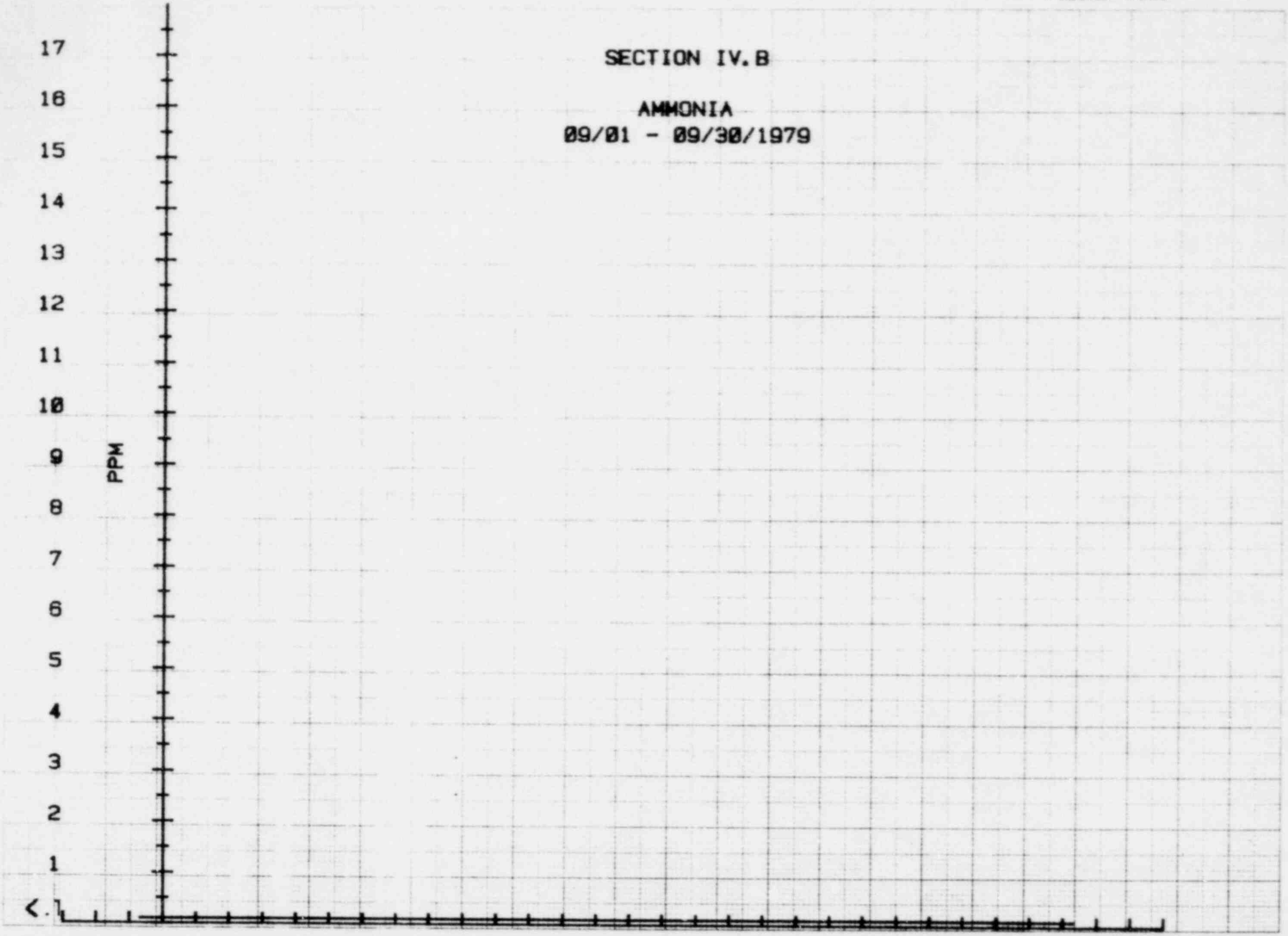
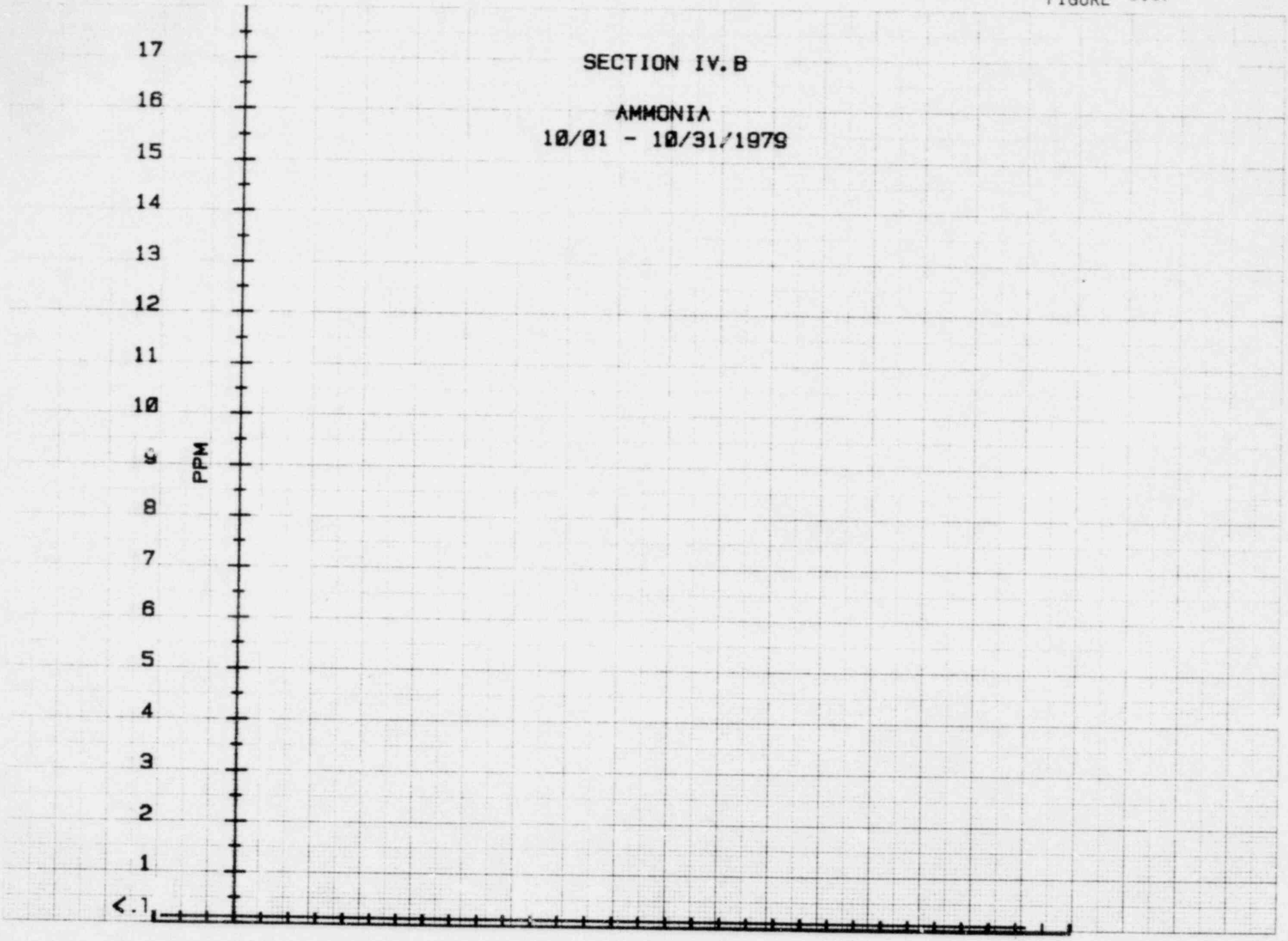

SECTION IV.B
AMMONIA
09/01 - 09/30/1979
PPM
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
<.1

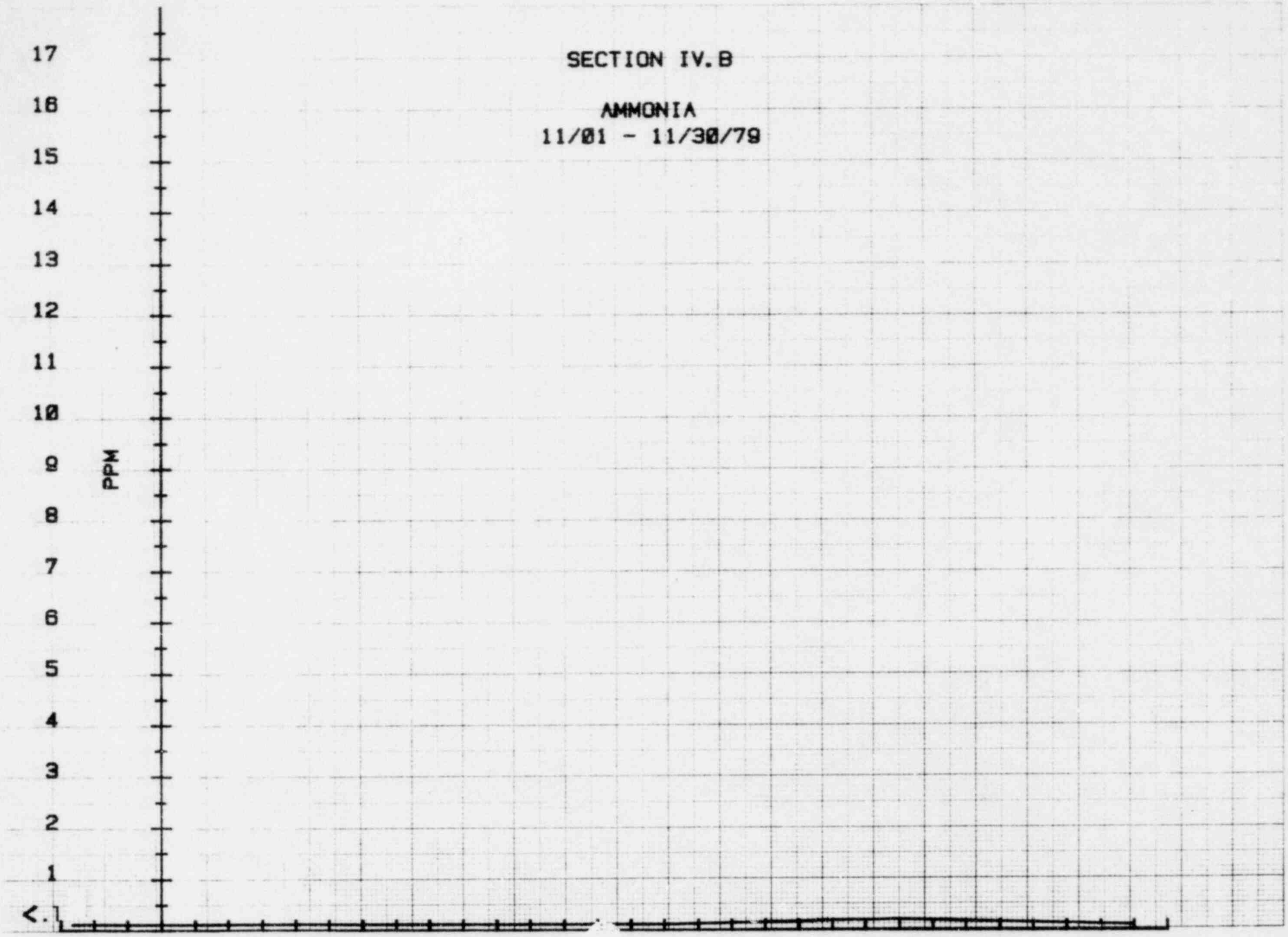
FIGURE 3.67



SECTION IV.B

AMMONIA
10/01 - 10/31/1979

FIGURE B.68


SECTION IV.B
AMMONIA
11/01 - 11/30/79
PPM
17
16
15
14
13
12
11
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9
8
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6
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4
3
2
1
<.1

FIGURE B.69

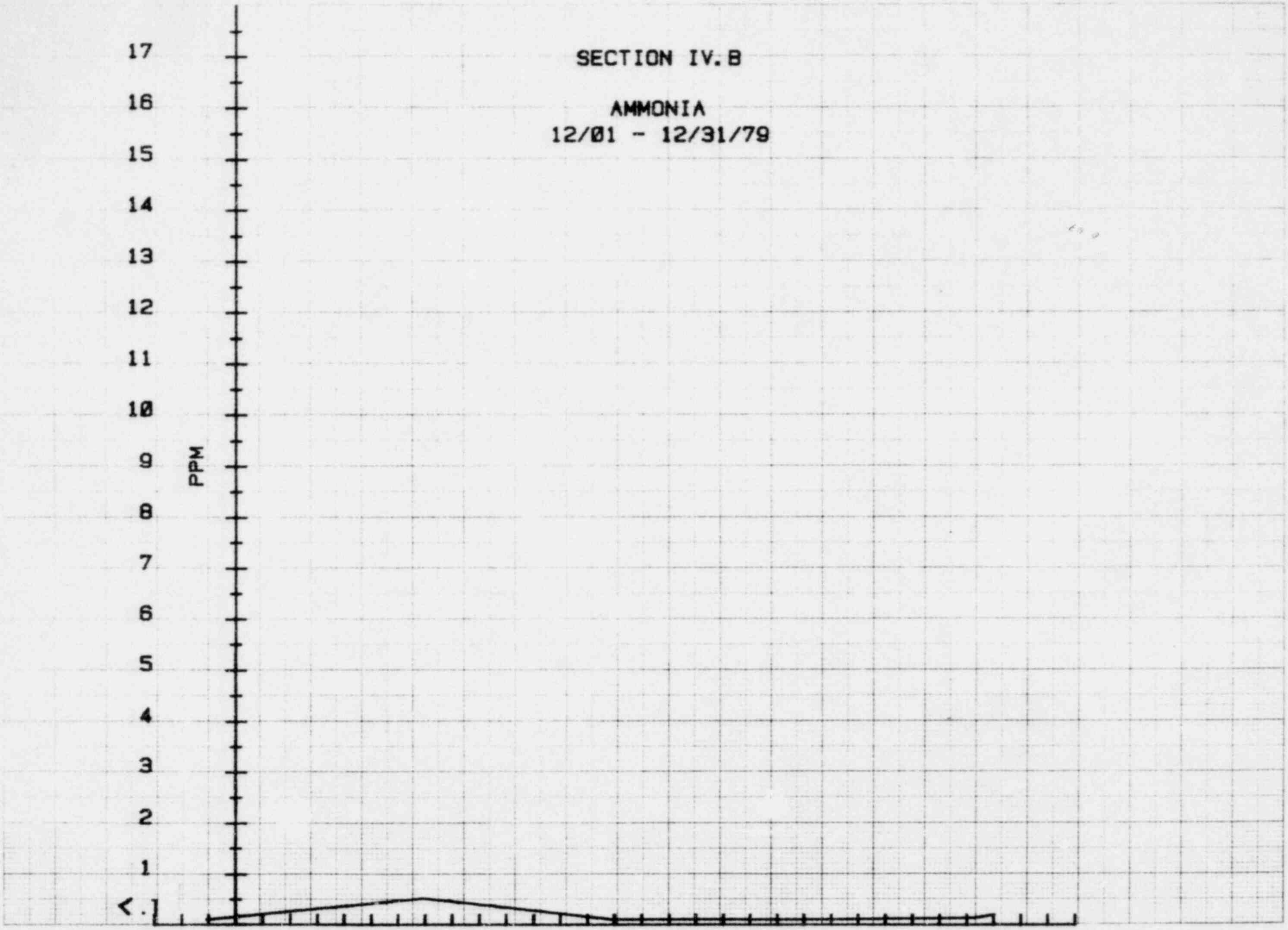

SECTION IV.B
AMMONIA
12/01 - 12/31/79
PPM
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
<.1

FIGURE B.70

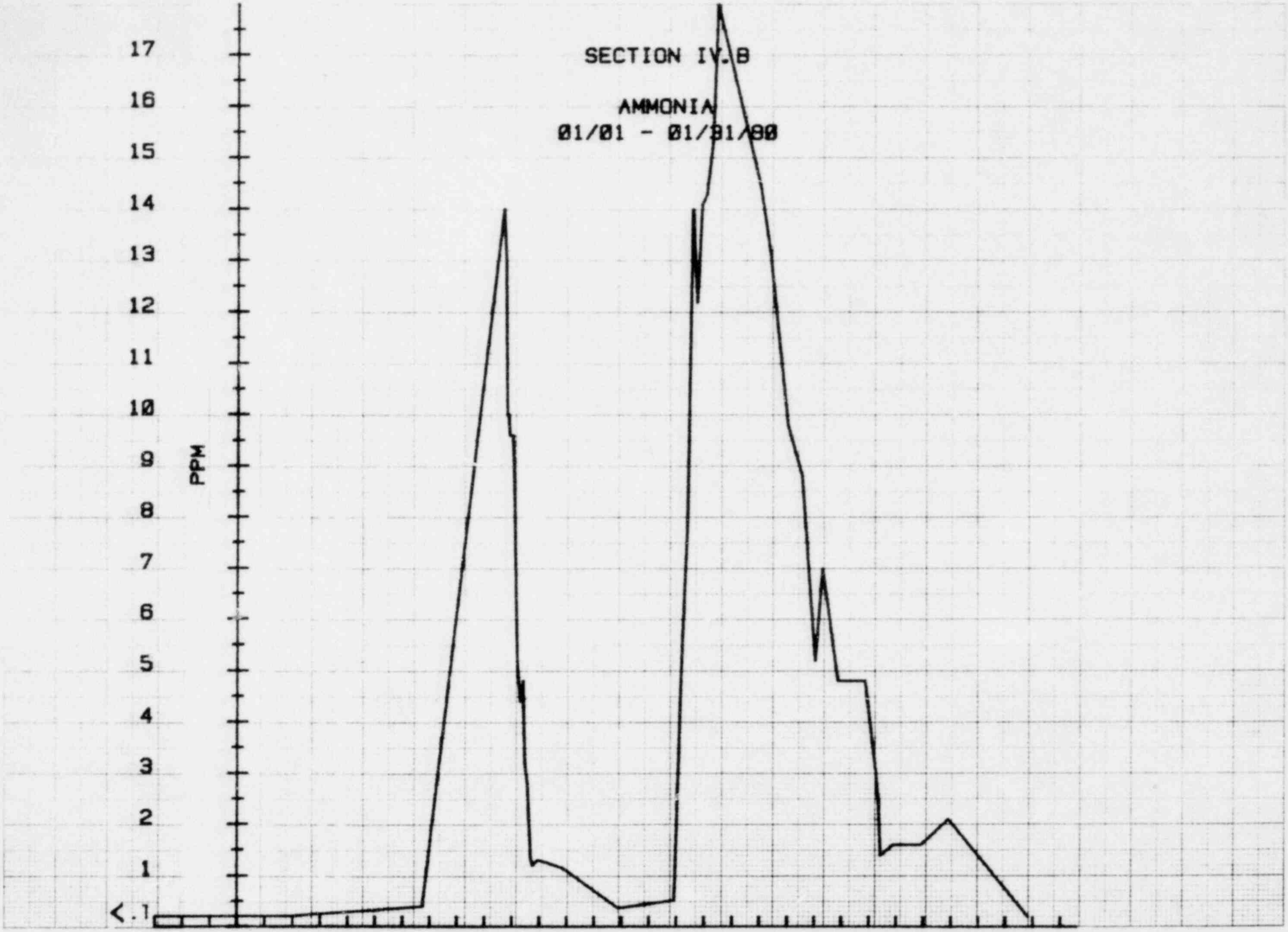
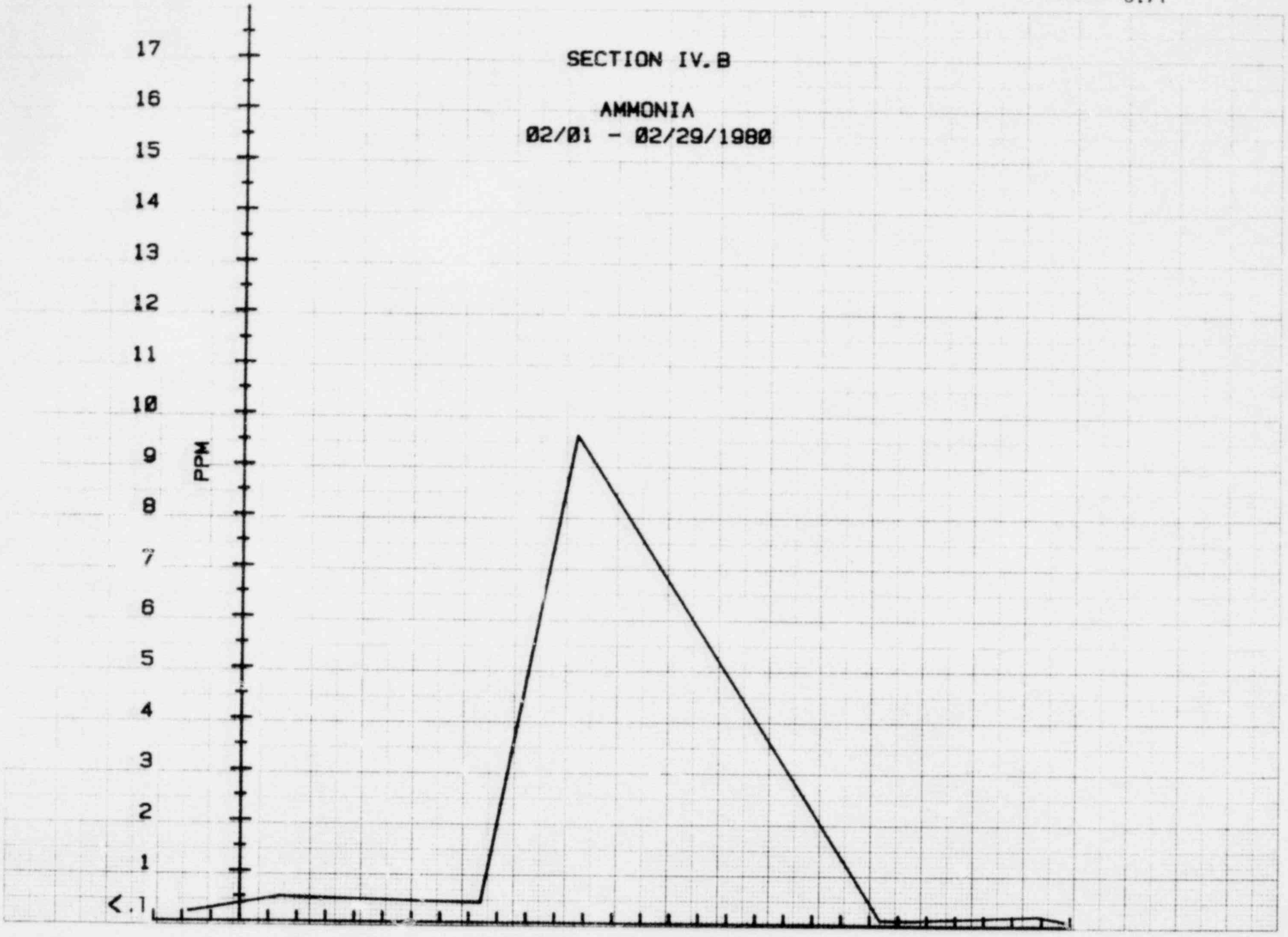

SECTION IV.B
AMMONIA
01/01 - 01/31/80
PPM
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
<.1

FIGURE B.71


SECTION IV.B
AMMONIA
02/01 - 02/29/1980
PPM
17
16
15
14
13
12
11
10
9
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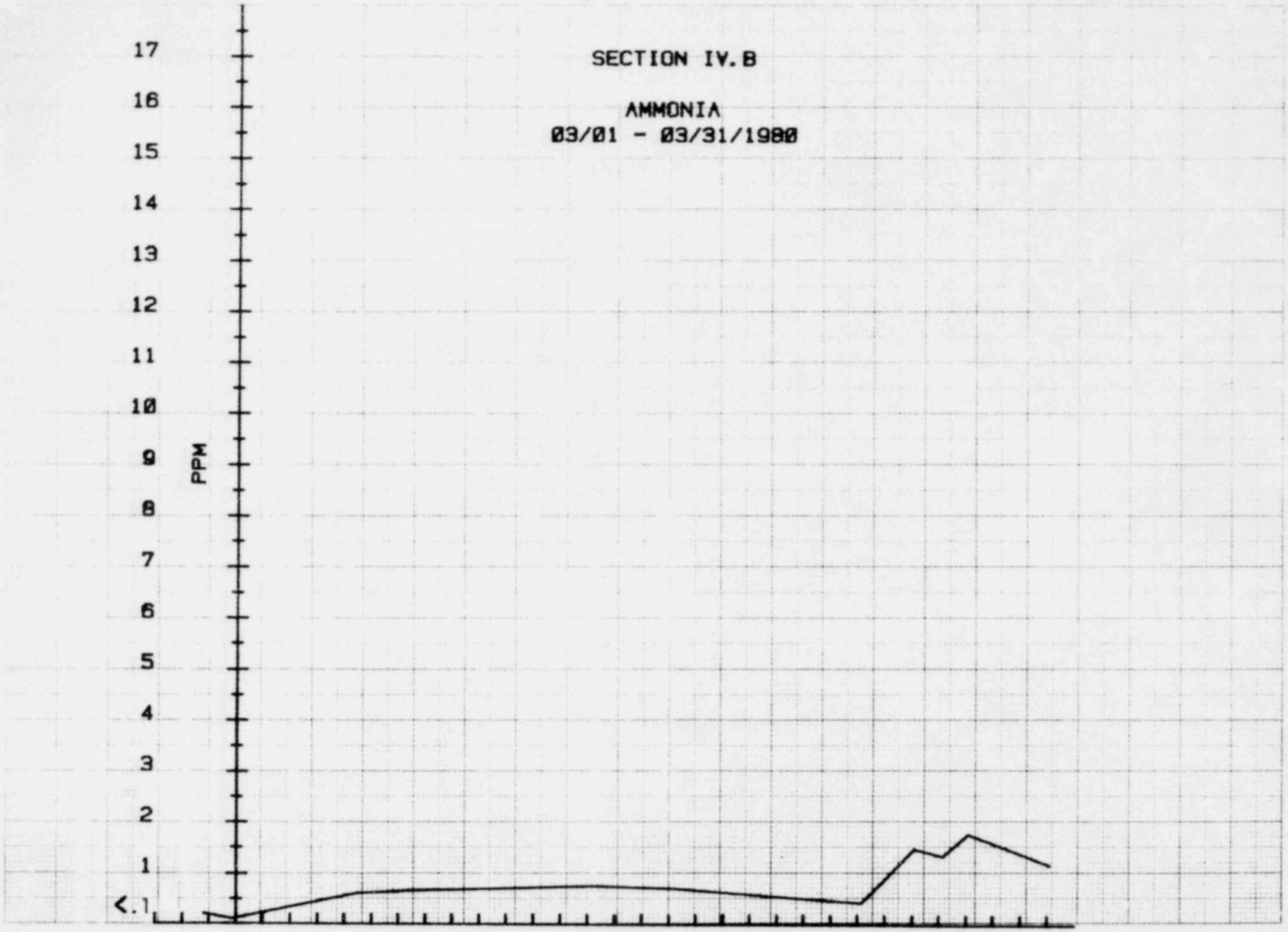
6
5
4
3
2
1
<.1

FIGURE B.72



SECTION IV.B

AMMONIA
03/01 - 03/31/1980

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 resson 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 ($liOH.H_2O$) additions to the RCS were not coordinated with the purification system lineup. As a result, obersved 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.

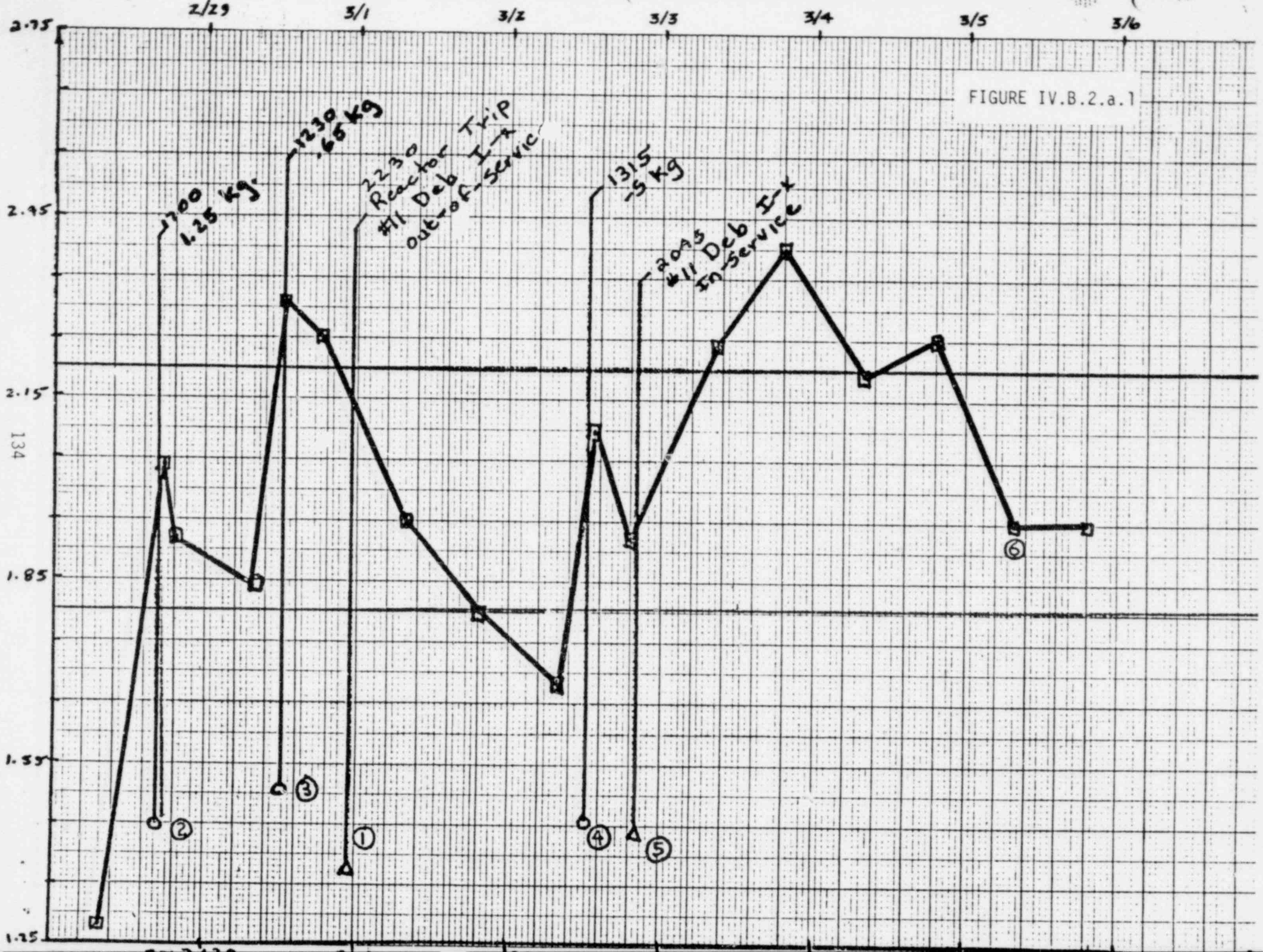


FIGURE IV.B.2.a.1

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. Oyygen 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 treatement 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.

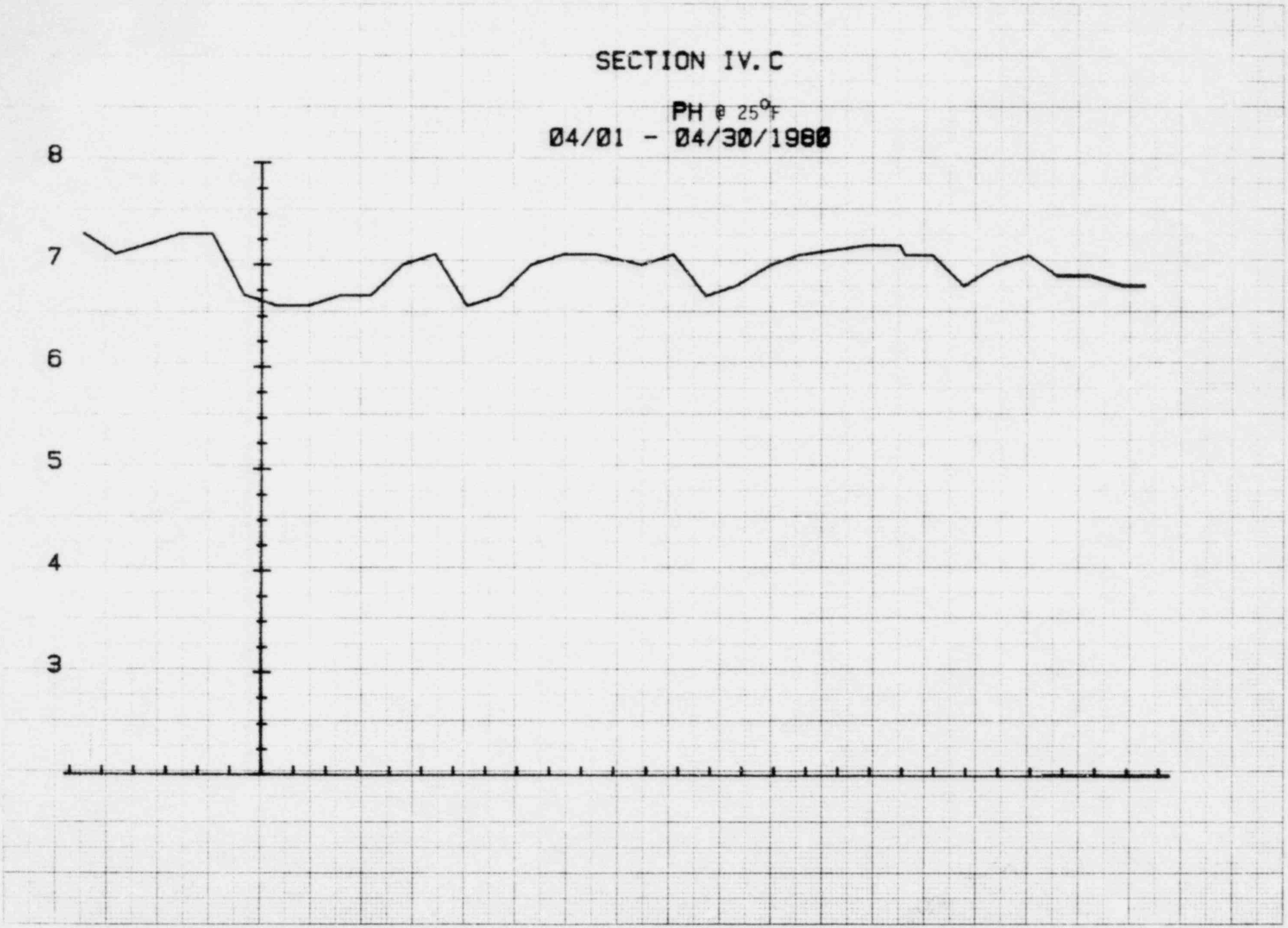
(5) Hydrogen (Figure C.5) was controlled within the upper portion of the allowable band to ensure an adequate hydrogen inventory in the RCS.

(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



SECTION IV.C

PH @ 25°F
04/01 - 04/30/1980

FIGURE C.2

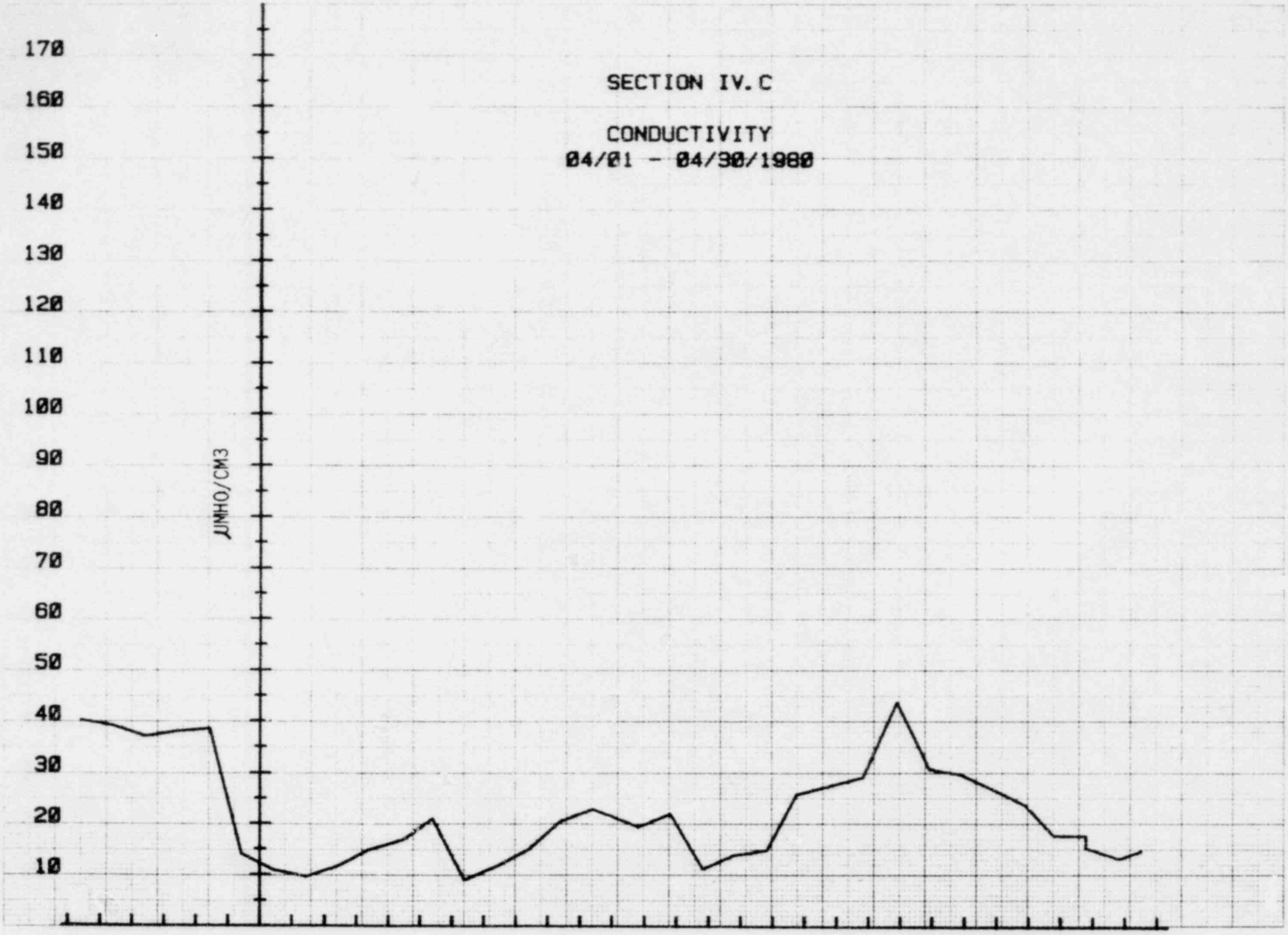
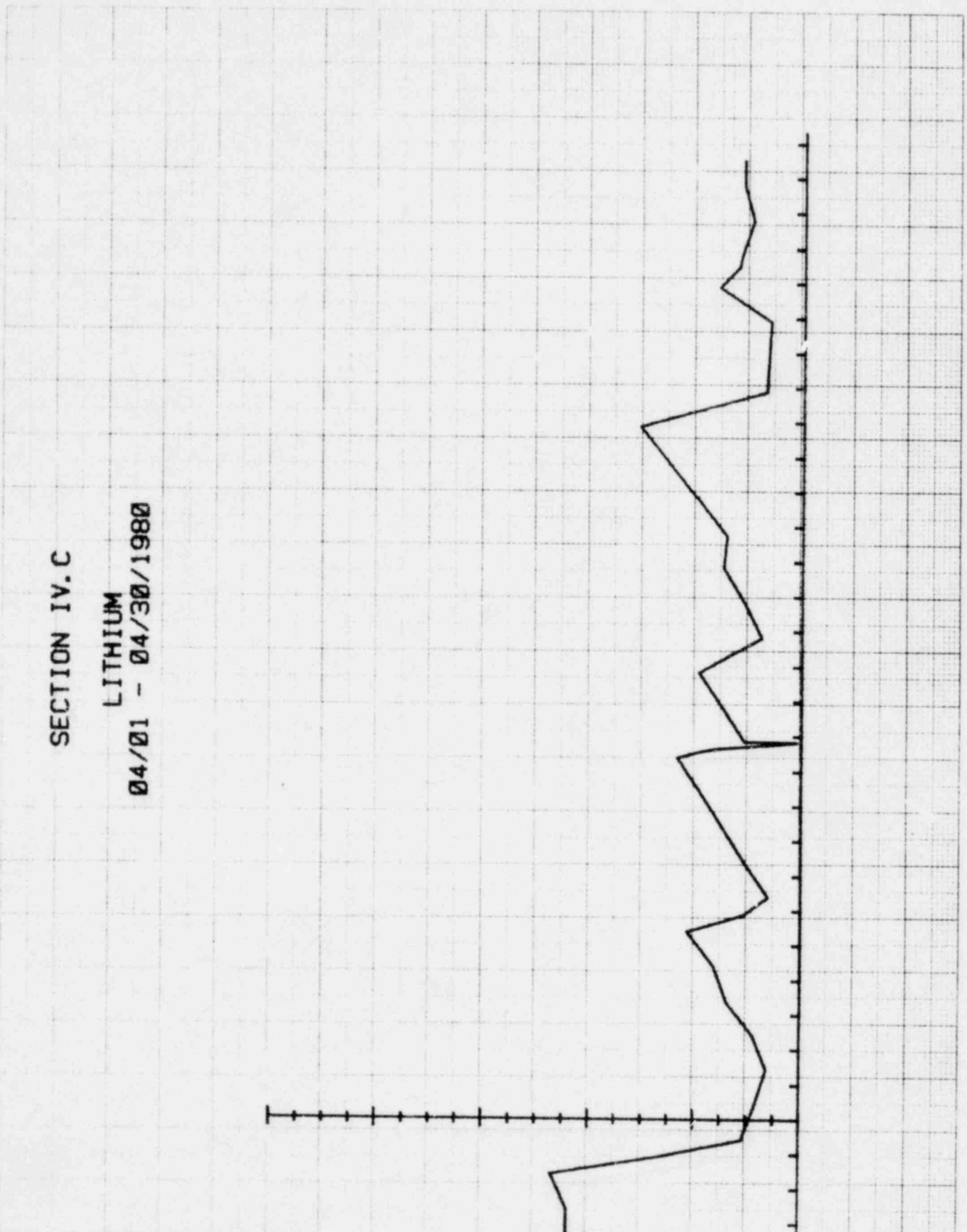

SECTION IV.C
CONDUCTIVITY
04/01 - 04/30/1980
µMHO/CM3
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10

FIGURE C.3



SECTION IV.C

LITHIUM
04/01 - 04/30/1980

FIGURE C.4

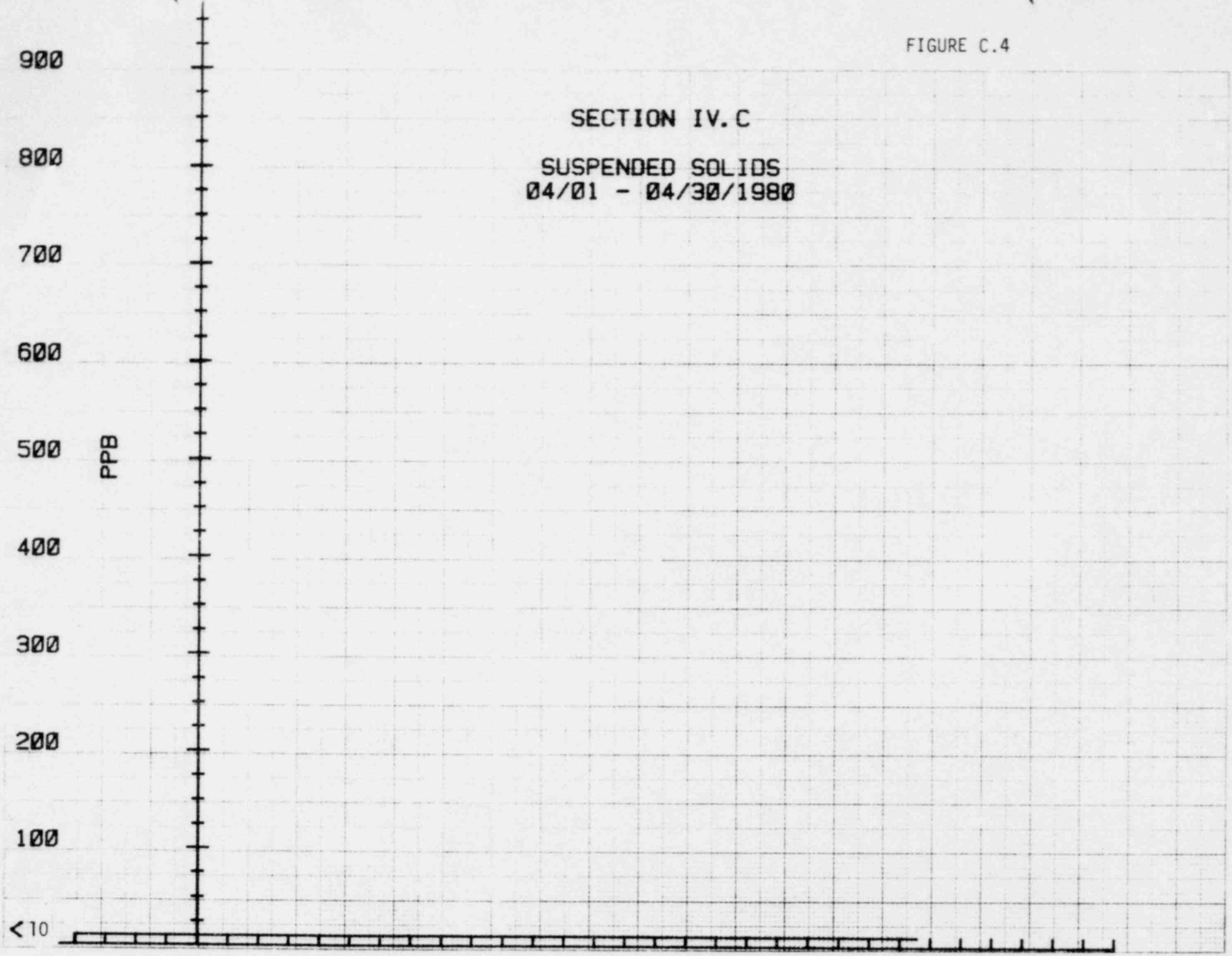

SECTION IV.C
SUSPENDED SOLIDS
04/01 - 04/30/1980
PPB
900
800
700
600
500
400
300
200
100
<10

FIGURE C.5

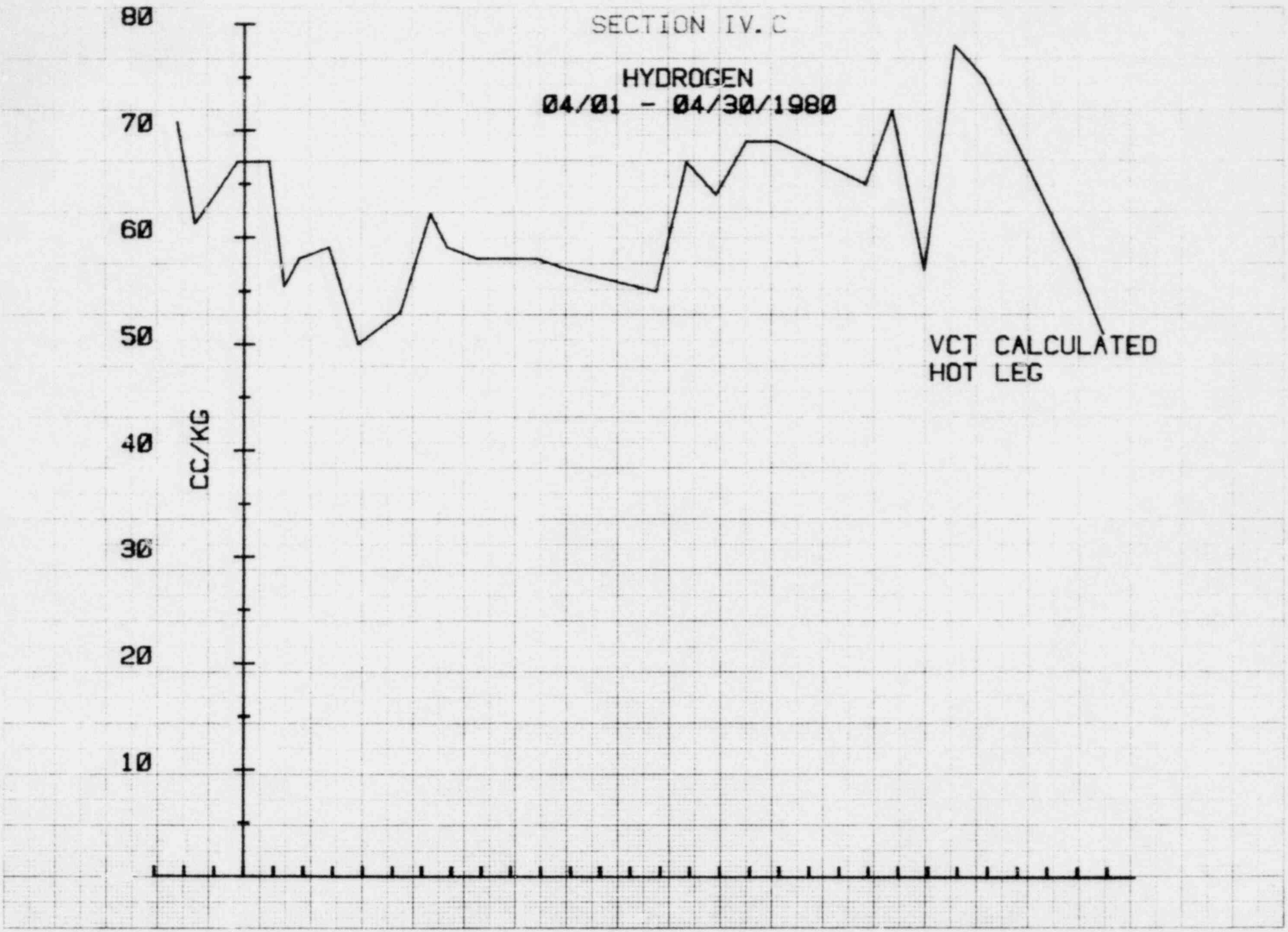

SECTION IV.C
HYDROGEN
04/01 - 04/30/1980
80
70
60
50
40
30
20
10
CC/KG
VCT CALCULATED
HOT LEG

FIGURE C.6

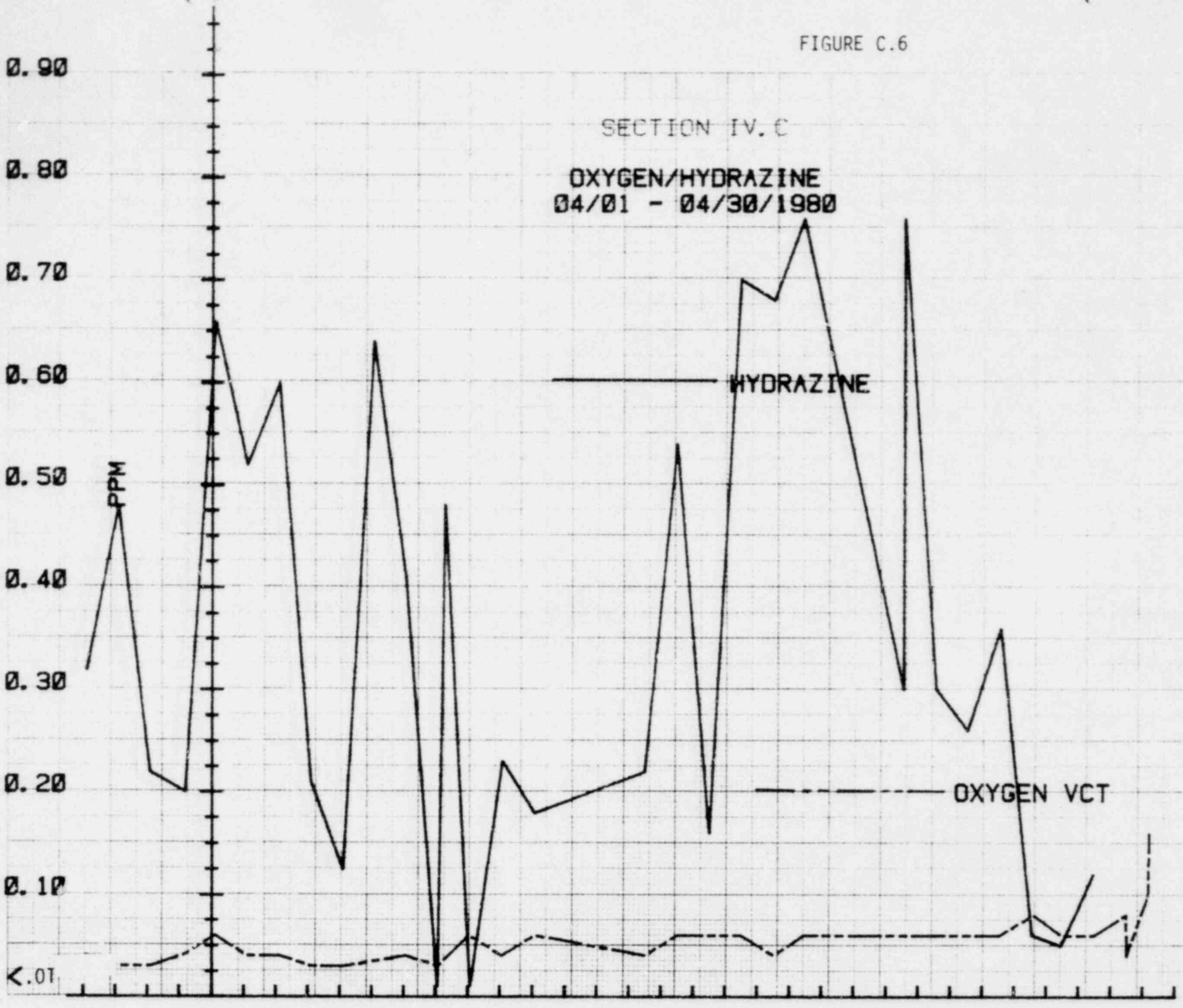
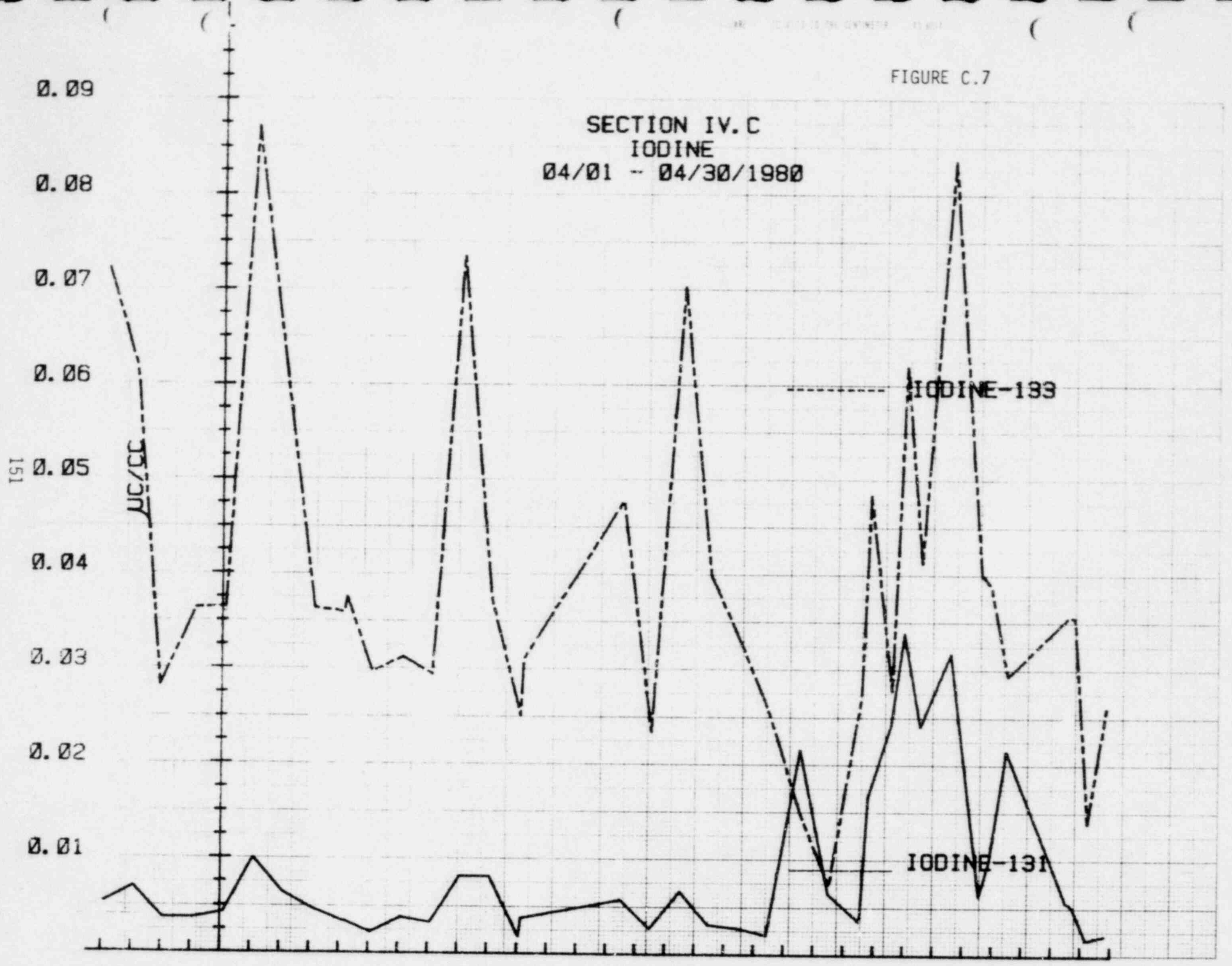

SECTION IV.C
OXYGEN/HYDRAZINE
04/01 - 04/30/1980
HYDRAZINE
OXYGEN VCT
PPM
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
<.01

FIGURE C.7



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

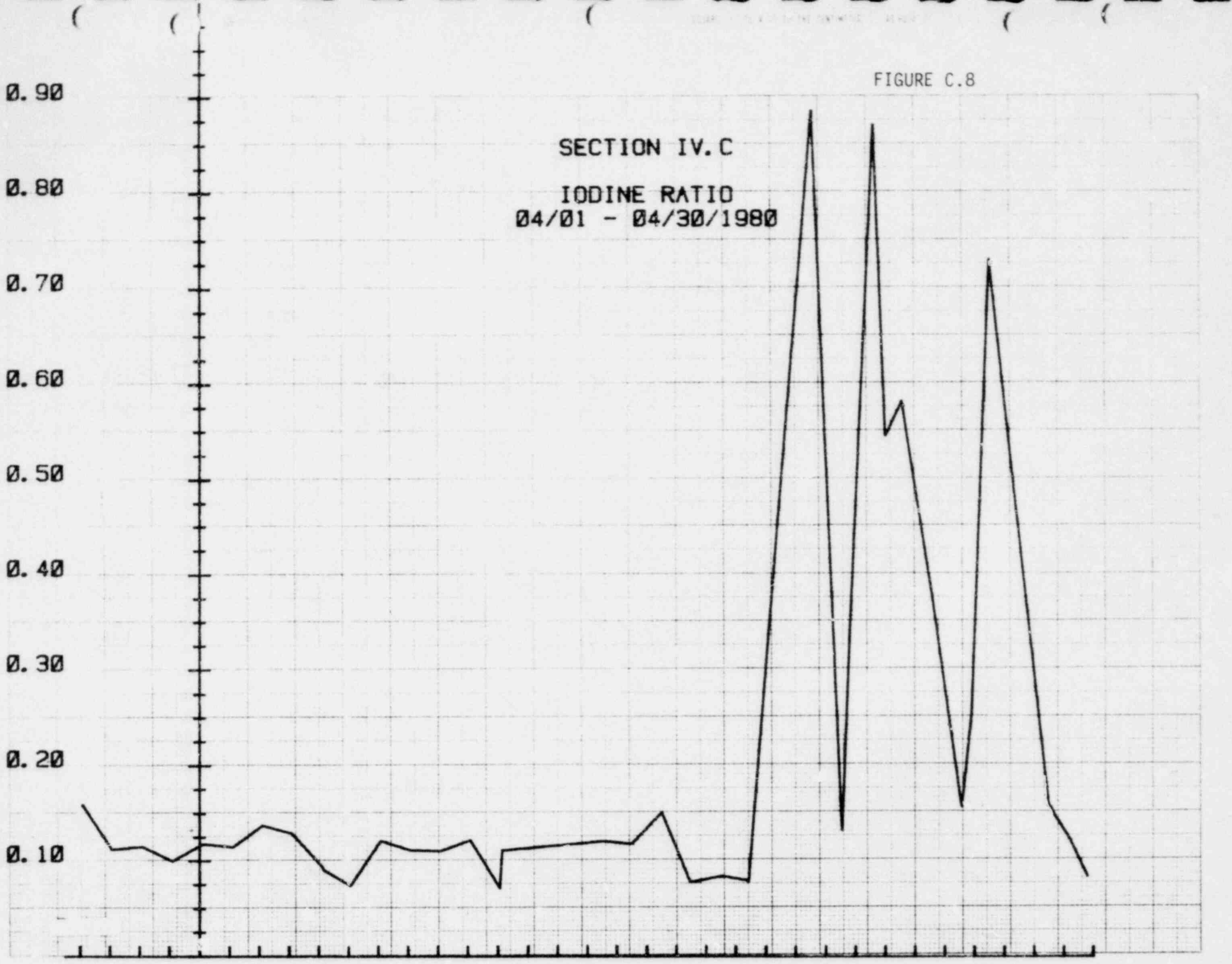
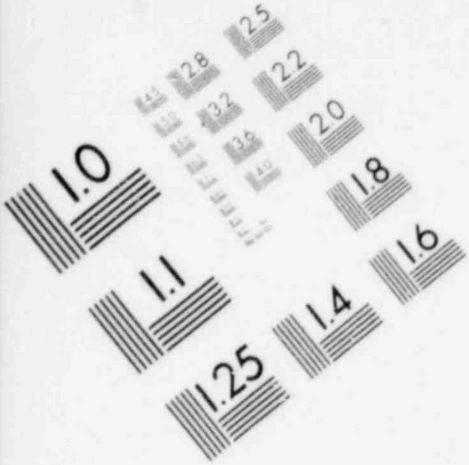


FIGURE C.8

SECTION IV.C

IODINE RATIO
04/01 - 04/30/1980



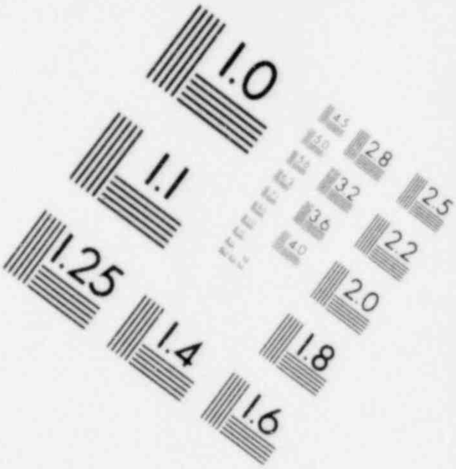
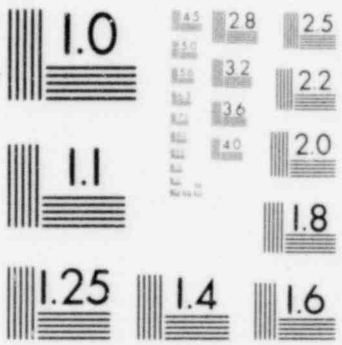
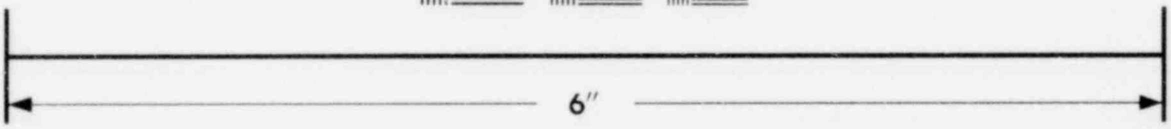
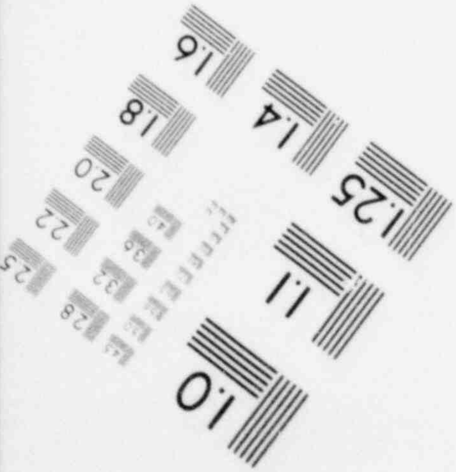
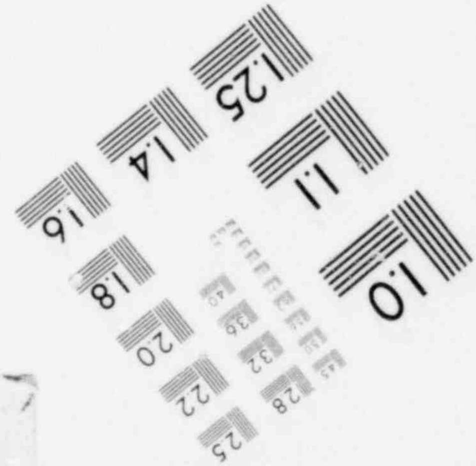


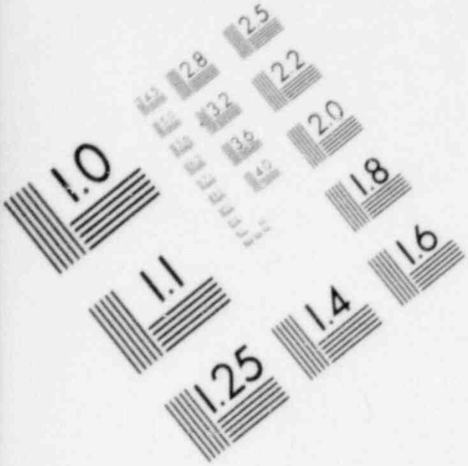
IMAGE EVALUATION TEST TARGET (MT-3)











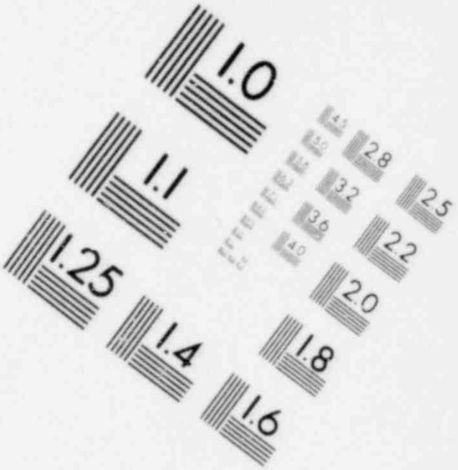
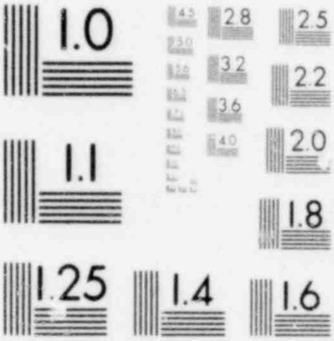
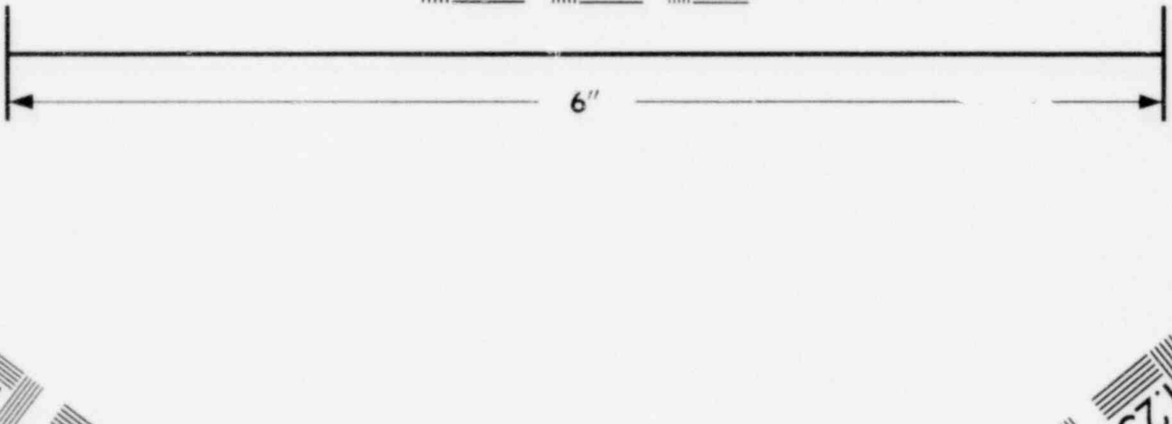
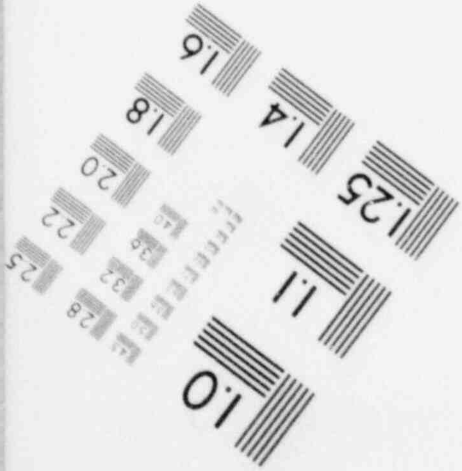


IMAGE EVALUATION TEST TARGET (MT-3)







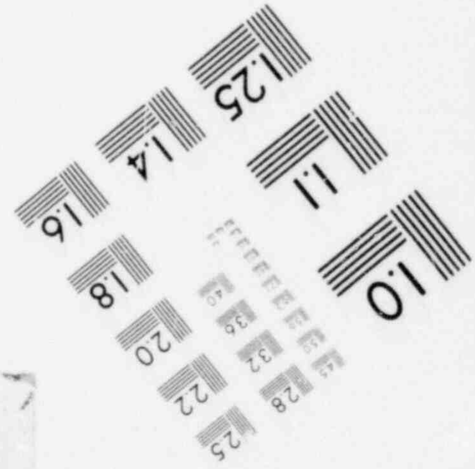
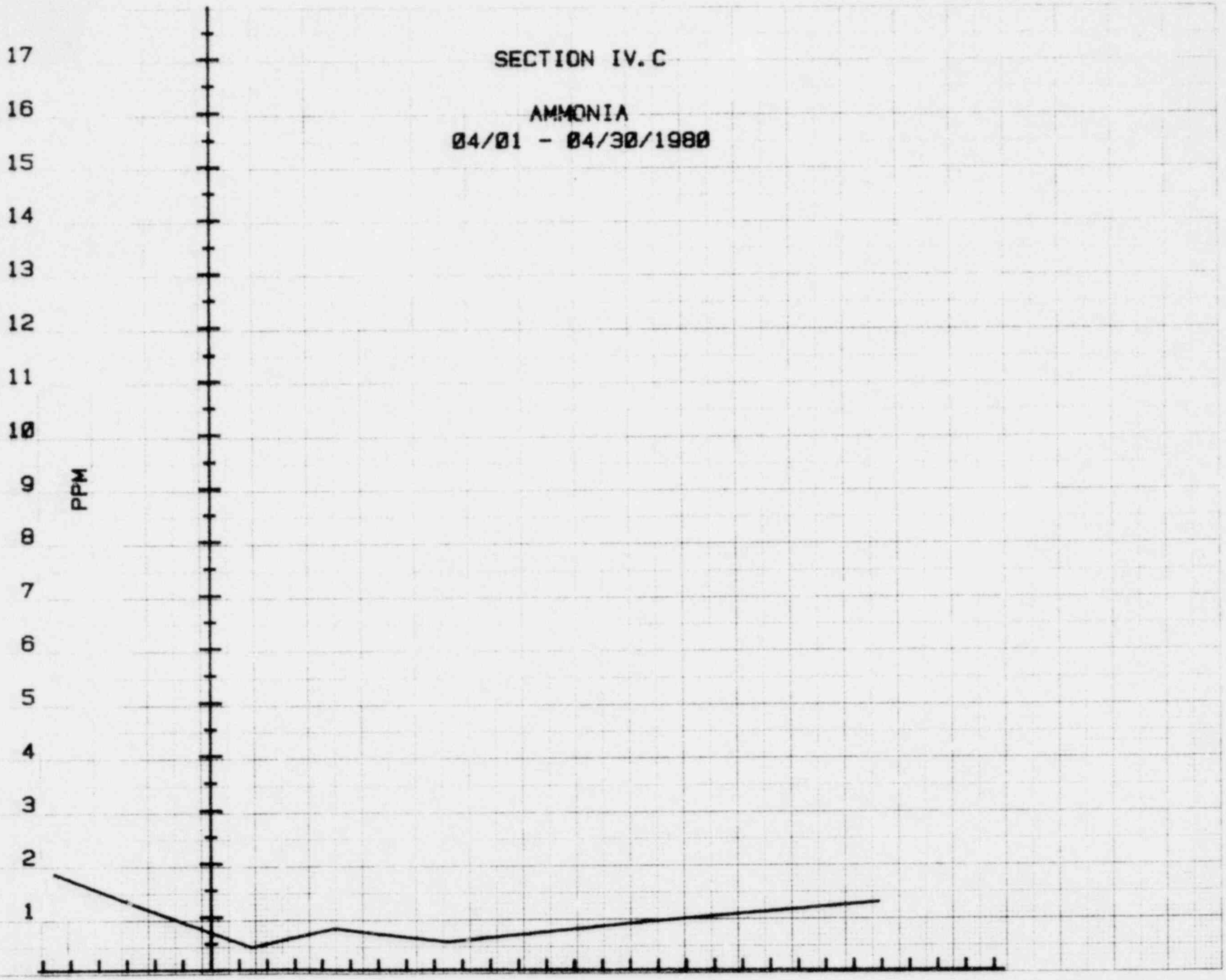


FIGURE C.9


SECTION IV.C
AMMONIA
04/01 - 04/30/1980
PPM
17
16
15
14
13
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11
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1

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 equlibrium).

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.

Parameters	Pre-Episode Nominal Value	Post-Episode Nominal Value	Post-Episode Specification
1) pH @ $25^{\circ}C$ (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.

ATTACHMENT (1a)

INDEX OF WATER CHEMISTRY AND RADIOCHEMISTRY PROCEDURES MANUAL - RCP 1

		CURRENT REV #
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*	Companent 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 (1D)

INDEX OF WATER CHEMISTRY AND RADIOCHEMISTRY PROCEDURES MANUAL - RCP 1

		CURRENT REV. #
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 Chliform 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

INDEX OF WATER CHEMISTRY AND RADIOCHEMISTRY PROCEDURES MANUAL - RCP 1

		CURRENT REV. #
1 - 1009	Determination of $\overline{E}$	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

*Required POSRC Review

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/$\bar{E}$ 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 β, γ 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
. $\bar{E}$ 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 $>$250 F.

(7) Hydrogen must be maintained within these limits for all plant operation above 1MWT. Less than 5cc H_2/kg H_2O (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.

ATTACHMENT (3a)

TABLE 3-3

SUMMARY OF REACTOR COOLANT CHEMISTRY SPECIFICATIONS

Analysis	Precore	Core Loading	Operating
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	----	----	$<10 \frac{cm^3\ (STP)}{kg\ H_2O}$ prior to a depressurization 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 ·	----	----	$10 - 50 \frac{cm^3 (STP)}{kg(H_2O)}$ (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 ^{7}Li maintain 1-2 ppm Li until saturation is reached (indicated by [illegible] breakthrough), then revert to 0.2 - 1.0 ppm ^{7}Li. 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 Frequency(a)	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_2H_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_2O	1.Add H_2 as required. 2.Degas as required.	<5 cm^3(STP)/kg H_2O before securing reactor coolant pumps
Total Dissolved Gas	Hot Leg Loop	AR	<10 cm^3(STP)/ kg H_2O prior to shutdown	1.Degas as required.	

SPECIFICATION SHEET NO. 3-3

SYSTEM REACTOR COOLANT - OPERATING (Continued)

Analysis	Sample Location	Sampling Frequency[(a)]	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 decomposition or radiolytic combination of N_2 and H_2.
Lithium	1. Hot Leg Loop or PF Inlet	Daily; after additions; and AR; (Note 1)	0.2 to 1.0 ppm	1. Initiate flow to delithiating bed if high. 2. Add Li-7 if low.	(e) To determine when when bed saturation takes place during lithiation.
	2. IX Outlet[(e)]	1			
Boron	1. PF Inlet or Hot Leg Loop	5	(f)	Add boric acid or makeup as required.	(f) Boron concentration varies with burnup. 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)		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.
	5. IX Outlet (when deborating)	1	(f)		
	6. Pressurizer	1	(f)		
Chloride	1. PF Inlet or Hot Leg Loop	5	Less Than 0.15 ppm	1. Check IX Outlet	
	2. IX Outlet	1		2. Initiate or increase purification flow.	
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. Isolate and shift columns.	
	4. Volume Control Tank Liquid	1		5. Replace resin bed, as required.	

SPECIFICATION SHEET NO. 3-3

SYSTEM REACTOR COOLANT - OPERATING (Continued)

Analysis	Sample Location	Sampling Frequency(a)	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(l) (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.	(l)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. (n)These will indicate the ability of the filter and IX bed to remove the solids.
2.Total Solids	Reactor Plant Makeup Tank	1	Less Than 0.5 ppm	Bleed and Feed or replace water to reduce solids level. Initiate or increase purification flow.	
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 $\overline{E}$ (g)		
Tritium	1.PF Inlet or Hot Leg Loop 2.Reactor Makeup Water Tank	1 2Y	(g) Concerning Waste disposal		

SPECIFICATIONS AND SURVEILLANCE
CVCS SYSTEMS

TABLE 1

	Analysis Procedure/Method	Specification	Frequency
A.	Ion Exchangers		
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.	Filters		
1.	Suspended Solids/911	DF = 10 (min)	1/M
C.	VCT		
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 Procedure/Method	Specification	Frequency (1)
1. pH @ 25°C/902	5.8 to 8.0	5/W
2. Conductivity/901	2.0 umho/cm3 (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 Demineralizer Effluent (MWS Demin. Effluent)	1. Continuous In Line Monitor 2. Daily Grab Sample 3. Prior to putting train on line	<1.0 μmho/cm	1.0-2.0[a] μmhos/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 μmhos/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 (6b)

SPECIFICATION SHEET NO. 2-1

SYSTEM MAKEUP WATER (Continued)

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 in servies 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 theRCS, 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 stochiometric 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 inpsection program forthe 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 theroetically calculated oxygen levels with observed oxygen levels based on the overall decomposition reaction:

$$2H_2O_2 \rightarrow 2H_2O + O_2$$

The data shows that the last peroxide addition resulted in close to predicted oxygen levels indicating that equilbrium 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.

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 μCi/cc as opposed to the baseline data of 6×10^{-3} μCi/cc and the normal shutdown levels of 4×10^{-1} to 8×10^{-1} μCi/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 cleanup 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.

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 H_2O_2 TREATMENT OF U-1 RCS

1/25/80	0830 hrs.	RCS Hydrogen 18.2 ccH_2/kg H_2O
	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_2O
	0245	Started 12B RCP Stop 11B RCP
	0400	RCS Hydrogen 7.8 ccH_2/kg H_2O
	0446	In Mode 4
	0600	RCS Hydrogen 4.5 ccH_2/kg H_2O
	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

ADDITION TIME	VOLUME ADDED(LITERS)	THEORETICAL OXYGEN(PPM)	OBSERVED OXYGEN(PPM)	RATIO THEORETICAL/OBSERVED
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

UNIT 1	Co-58/Co-60 ACTIVITY(uCi)	Co-58/Co-60 RATIO
Outage #2	2.38E-1/1.30E-1	1.8
Outage #3	5.26E-1/1.29E-1	4.1
UNIT 2		
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 FACTORS

Co-58 Activity (μCi/ml)

DATE	TIME	INLET	OUTLET	DECONTAMINATION FACTORS[1]
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]

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[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

2. "Fort Calhoun-1, Reactor Coolant System Peroxide Treatment 11/10/74 to 11/13/74", Principal Investigator-D. J. Morgan

3. RCP 1-1206 "Reactor Coolant System Hydrogen Peroxide Treatment" Revision 0, January 9, 1980

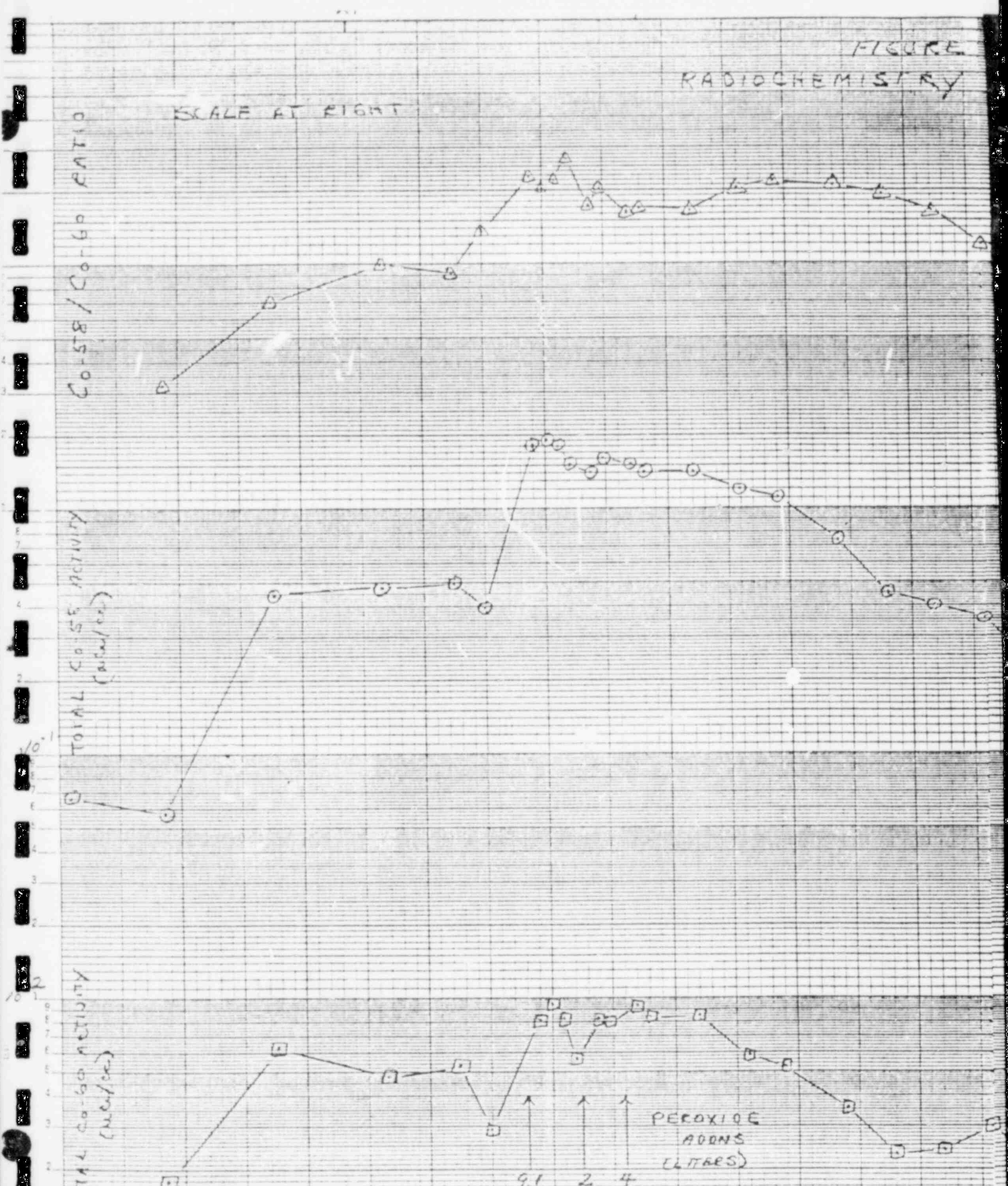
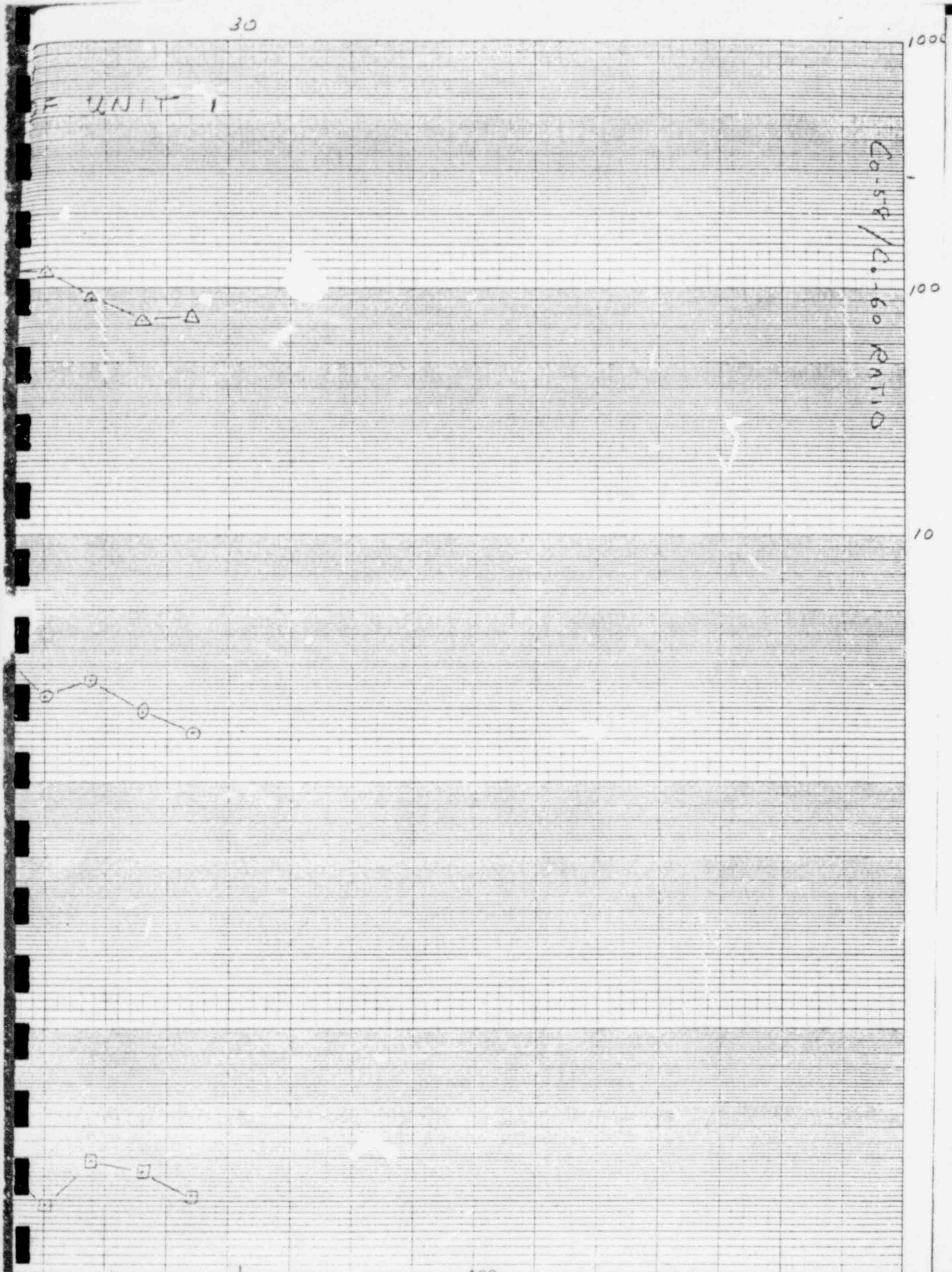


FIGURE
RADIOCHEMISTRY
SCALE AT RIGHT
Co-58 / Co-60 RATIO
TOTAL Co-58 ACTIVITY (µCi/cc)
TOTAL Co-60 ACTIVITY (µCi/cc)
10⁻¹
10⁻²
10⁻³
PEROXIDE ADDNS (LITERS)
9.1
2
4
26
27
28
29
JANUARY 1980


30
F UNIT 1
1000
100
10
Co-58/Co-60 RATIO
2

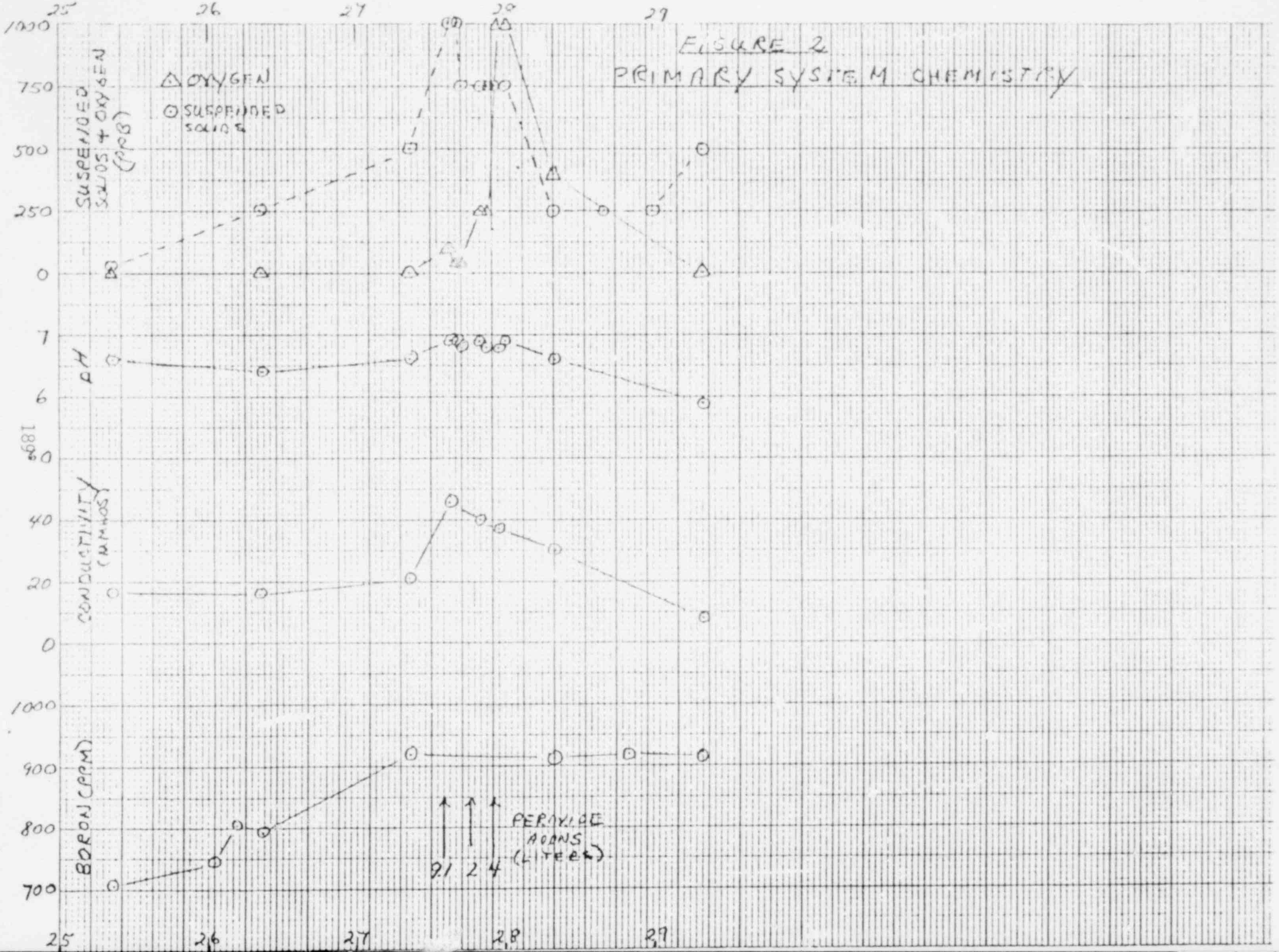


FIGURE 2
PRIMARY SYSTEM CHEMISTRY

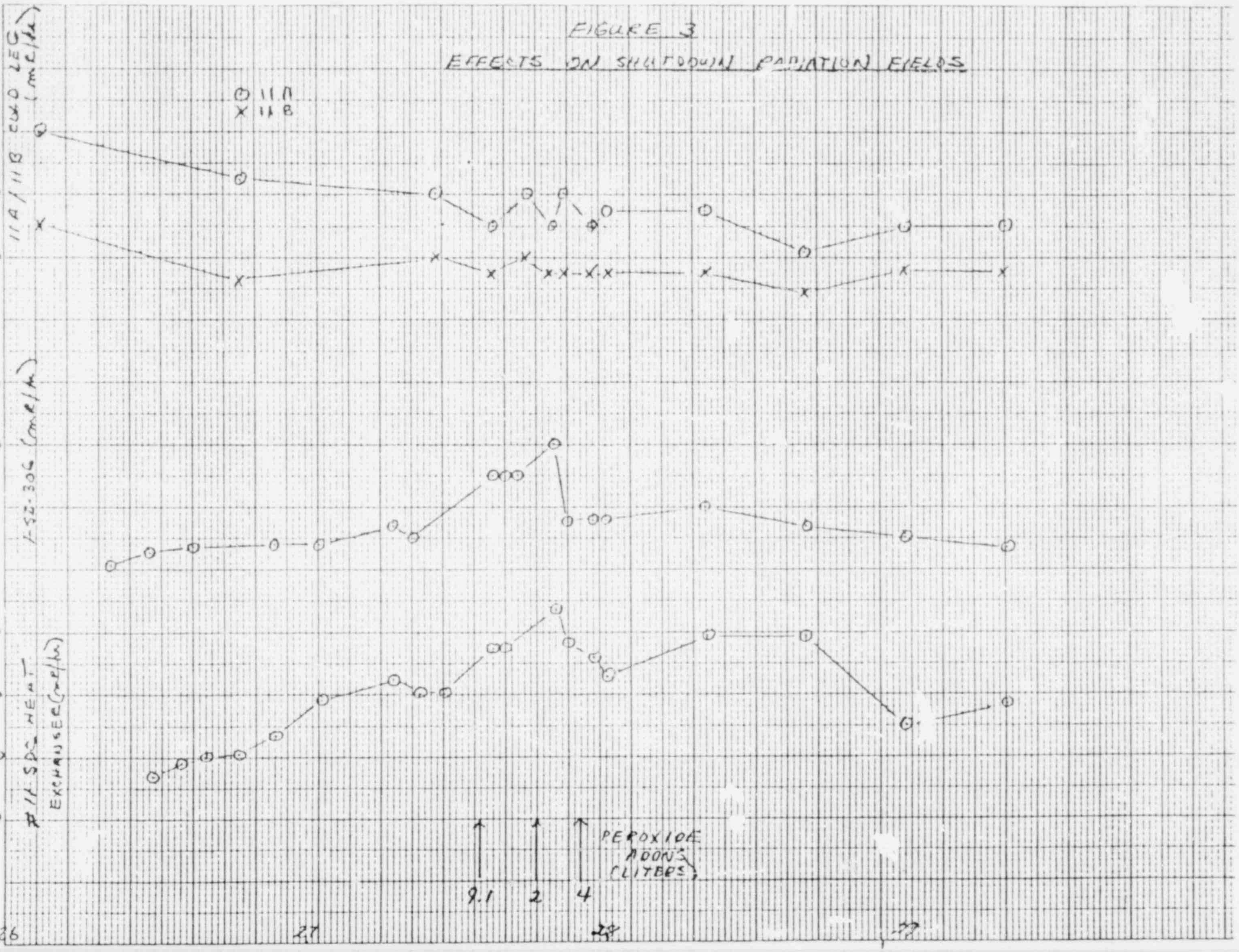
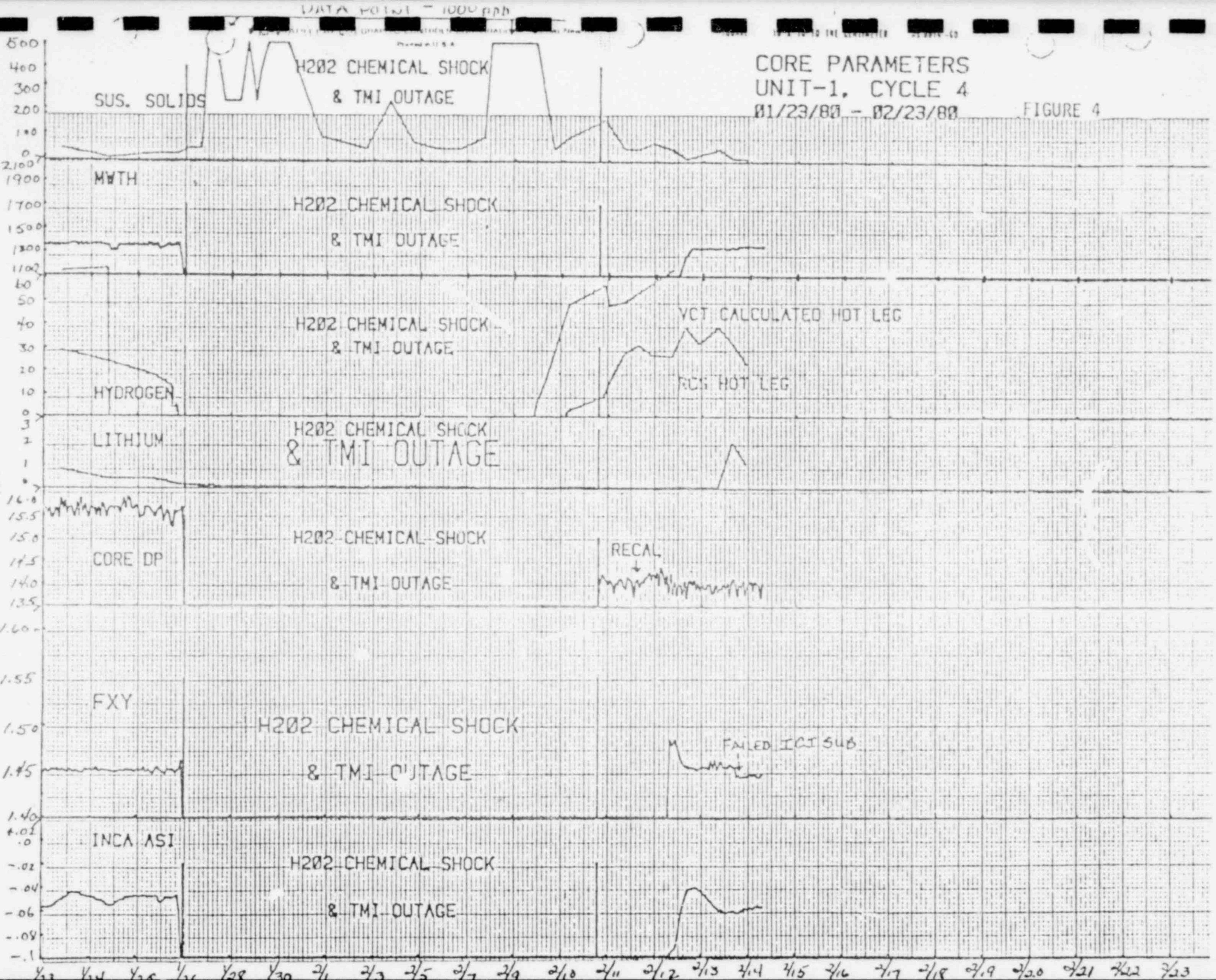


FIGURE 3
EFFECTS ON SHUTDOWN RADIATION FIELDS
⊙ 11A
X 11B
11A/11B COLD LEG (mR/hr)
300
200
100
0
1-SZ-306 (mR/hr)
300
200
100
0
#11 SDC HEAT EXCHANGER (mR/hr)
300
200
100
0
PEROXIDE ADDNS (LITERS)
9.1
2
4
26
27
28
29



CORE PARAMETERS
UNIT-1, CYCLE 4
01/23/80 - 02/23/80

FIGURE 4