LBL-12951
UC-64

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA, BERKELEY

EARTH SCIENCES DIVISION

PLUME SURVEY
OTEC-1 MIXED-WATER DISCHARGE
APRIL 11-12, 1981

Edward K. Noda, Paul K. Bienfang, William J. Kimmerer, and Ted W. Walsh

May 1981

Prepared for the U.S. Department of Energy under Contract W-7405-ENG-48

DISCLAIMER

LBL-12951

PLUME SURVEY

OTEC-1 MIXED-WATER DISCHARGE

April 11-12, 1981

Edward K. Noda[1]
Paul K. Bienfang[2]
William J. Kimmerer[3]
Ted W. Walsh[3]

Earth Sciences Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

[1]Edward K. Noda and Associates

[2]Oceanic Institute

[3]University of Hawaii, Hawaii Institute of Marine Biology

May 1981

This work was performed under Subcontract No. 4983902 between the University of Hawaii and Lawrence Berkeley Laboratory. The Lawrence Berkeley Laboratory is operated by the University of California for the U.S. Department of Energy under Contract W-7405-ENG-48. Matching funds for this project were provided by the State of Hawaii, Marine Affairs Coordinator, Office of the Governor and by the University of Hawaii, Hawaii Natural Energy Institute.

ACKNOWLEDGEMENTS

The authors would like to express sincere appreciation to the following individuals and organizations who provided invaluable services leading to a very successful completion of this plume survey; Jeri Edgar-Vogt and Eric O. Hartwig, Lawrence Berkeley Laboratory; Harley Sugiyama, Department of Public Works, City and County of Honolulu; Frederick M. Casciano, Ocean Innovators; James Szyper, Oceanic Institute; Christine Baer, Hawaii Institute of Marine Biology; David Creer, AECOS, Inc.; Tracor Marine; E-Tech; and a special appreciation to Larry Van Loon, Argonne National Laboratory.

This work was performed under Subcontract No. 4983902 between the University of Hawaii and Lawrence Berkeley Laboratory. The Lawrence Berkeley Laboratory is operated by the University of California for the U.S. Department of Energy under Contract No. W-7405-ENG-48. Matching funds for this project were provided by the State of Hawaii, Marine Affairs Coordinator, Office of the Governor and by the University of Hawaii, Hawaii Natural Energy Institute.

TABLE OF CONTENTS

I. INTRODUCTION

As part of the Department of Energy's (DOE) research, development and demonstration effort towards the ultimate goal of the commercialization of Ocean Thermal Energy Conversion (OTEC), DOE has contracted with the Lawrence Berkeley Laboratory (LBL), University of California to carry out a shipboard measurement program to provide baseline biological, chemical and physical oceanographic data at potential OTEC sites. Hawaii is a potential OTEC site region and LBL is sponsoring a research study with the University of Hawaii to obtain and analyze the required environmental data.

One of the objectives of this program is an assessment of the environmental effects of the mixed-water (cold and warm combined) discharge from the OTEC-1 system. In order to meet this objective a plume survey was undertaken by the University of Hawaii during April 11-12, 1981 and the results of this survey are described herein.

Two specific objectives were envisioned for the plume survey.

1. Locate and map the physical extent of the thermal plume, both vertically and horizontally and determine the dilution of the discharging effluent with ambient waters as a function of location. One of the primary purposes of this task is to provide prototype data for comparison with analytical/computer models of the thermal plume. In this regard the near-field region of the thermal plume out to about 300m was considered the first priority.

2. Once the plume location has been defined, a biological and water quality sampling program would be carried out both within and out of the plume. The water quality sampling program involved measurement of the following:

    a. Dissolved oxygen.
    b. Salinity.
    c. Nutrients.

The phytoplankton sampling program involved measurements of ATP, chlorophyll-a, and phaeopigments. The zooplankton program involved horizontal net tows both within and out of the plume.

II. DESCRIPTION, PROCEDURES AND OPERATION

Figure II.1 describes the general site location of the R/V Ocean Energy Converter (OEC), which houses the OTEC-1 system. The OEC is a converted T-2 tanker with an overall length of 160m (523.5 ft), beam of 21m (68 ft) and a depth of about 7.9m (26 ft). The mixed-water discharge exits from a single 1.8m diameter round port directed vertically downward just below the bottom of the hull at a water depth of about 8m. The discharge port is located about 41m forward of the OEC stern and about 2-3m inboard of the port side. Typical discharge rates encountered during the plume survey were about 9.8m^3sec (155,000 gpm) which results in a nominal vertically downward effluent exit velocity of 3.8m/sec.

The technique used to locate and map the plume extent and dilution was to inject a fluorescent dye tracer into the discharging effluent and track the plume using a fluorometer. Rhodamine WT dye was used as the tracer supplied in a 20% solution with a density of 1.2. The dye was injected into the system at the mixed-water discharge sump located approximately 45m forward of the discharge position. This sump is located just downstream of the cold water inflow and just upstream of the warm water inflow, which then proceeds to the mixed-water axial flow discharge pump. The dye injection flow rate was accurately controlled using a Masterflex peristaltic pump with a No. 7016 pump head. Prior to the plume survey the Masterflex pump system was calibrated and the calibration results are shown in Figure II.2.

The fluorometer used for this survey was a Turner Model III equipped with a No. 110-851 Far UV lamp, green primary filter No. 546, red secondary filter No. 2-60, No. 110-880 high volume continuous flow attachment and a No. 111-801 recorder. Dye samples obtained directly from the dye container were used to develop dye concentration calibration data for the fluorometer. Using these dye concentration standards a calibration factor of 0.000571 parts per million (ppm) dye per unit fluorometer reading was obtained for the continuous flow attachment and a factor of 0.00135 ppm dye per unit fluorometer reading was obtained for the discrete sample attachment.

In order to utilize the fluorometer system with the continuous flow attachment, sea water was pumped from depth using a Jacuzzi Model 354LR9-SI electric submersible pump of 1/3 hp operating with 115VAC. The pump system was equipped with 183m (600 ft) of 3/4 inch diameter water hose although during the plume survey only 122m (400 ft) were attached. A meter wheel/snatch block was used to control the depth of the submersible pump intake. To determine the residence time of the pump system, verification tests were performed by first submerging the pump intake until a stable fluorometer reading was obtained, then rapidly raising and lowering the pump intake through the air-water interface thereby injecting an air bubble into the system which is clearly registered by the fluorometer. The residence time was measured to be about 60 seconds.

In order to accurately determine the relative locations between the OEC and the survey vessel M/V El Greco, vessel positioning data was provided by

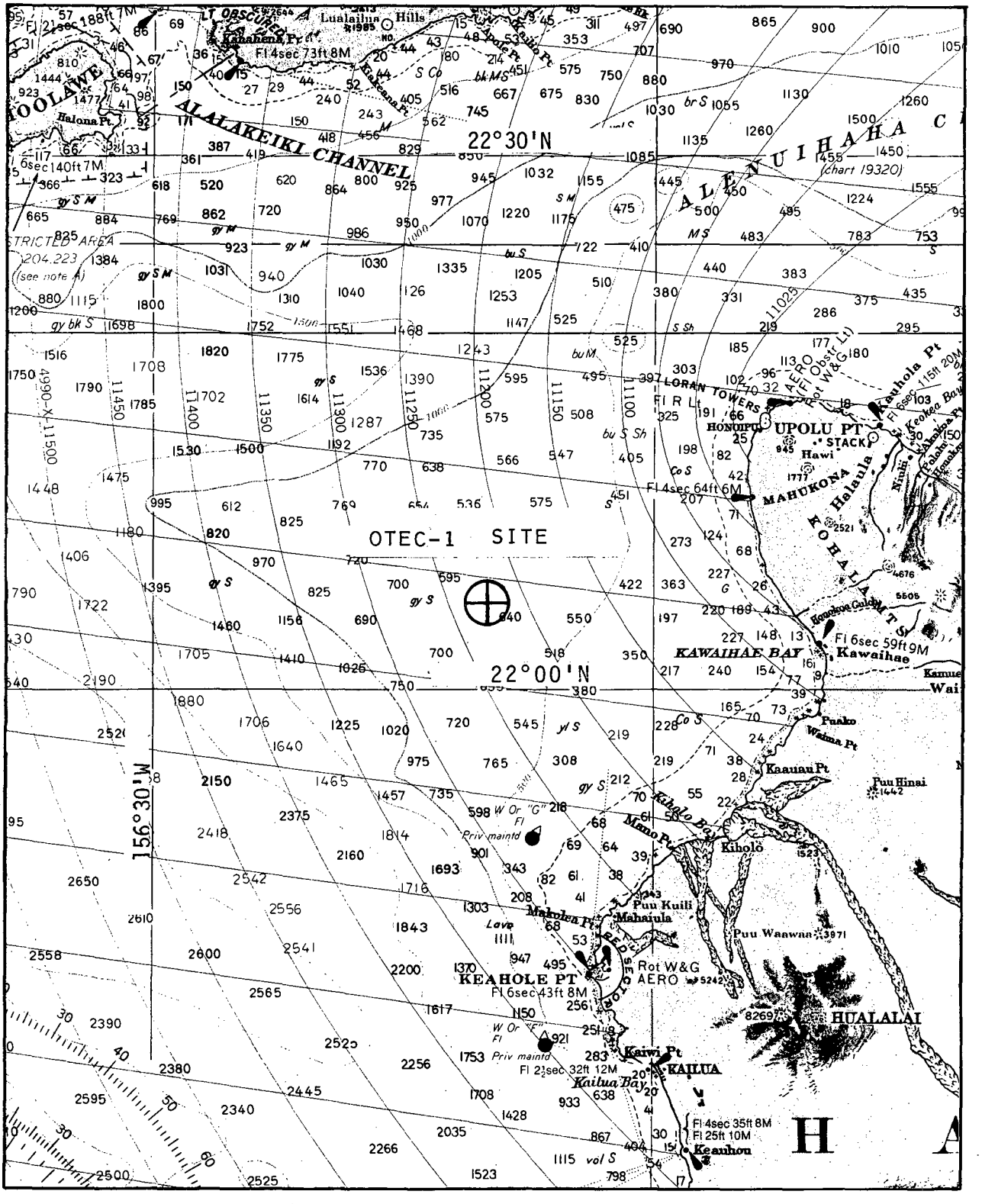


FIGURE II.1. OTEC-1 SITE LOCATION OFF KEAHOLE POINT, HAWAII

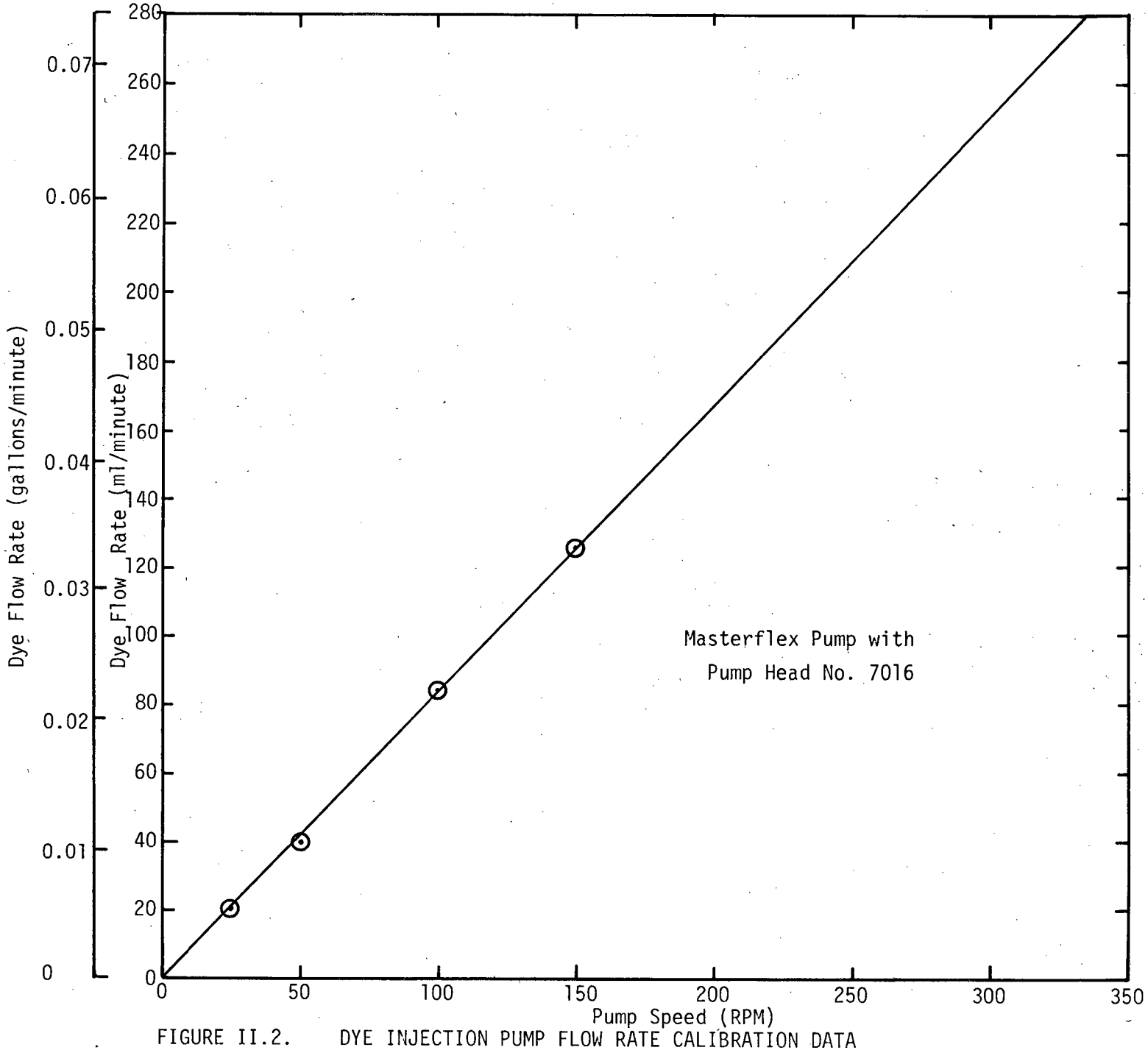


FIGURE II.2. DYE INJECTION PUMP FLOW RATE CALIBRATION DATA

two range-range electronic positioning systems. Onboard the OEC a Motorola Mini-Ranger III system with antenna located about 61m forward of the mixed-water discharge port served to locate the OTEC-1 platform. Onboard the survey vessel a Del Norte Trisponder system provided the navigation data where the antenna was located about 13m forward of the stern. Two shore transponder stations were utilized for both systems and the coordinates of these stations are given below.

Station Description	Coordinates	
	Latitude	Longitude
North Kohala	20°10.32'N	155°50.19'W
Kona	19°46.02'N	155°56.92'W

Pre-plotted range-range arcs were used to allow real-time plotting of both the OEC and survey vessel's position in order to orient the plume mapping operation.

During the night preceding the 0920 April 11, 1981 arrival of the survey vessel at the OTEC-1 site, the mixed-water discharge was started to stabilize the plume. At 0821, just prior to the arrival of the survey team, dye injection was initiated. Upon arrival of the survey vessel at the OTEC-1 platform, the dyed discharge was visually evident only very near the discharge location. An XBT probe (XBT No. 1) was launched into the plume approximately 3 meters downstream from the discharge and the temperature profile results as compared to a control profile (XBT No. 2) obtained 5 minutes later outside of the plume did indicate the possibility of a plume between 15-30 meters where a colder temperature was noted as compared to the control profile. Nevertheless both the limited vertical scale of the XBT recorder and the limited temperature sensitivity precluded general use of XBT probes to define the plume extent. XBT profiles are shown in Appendix A.

Plume mapping utilizing the fluorometer system was then initiated. A series of vertical profiles were first obtained at varying distances downstream from the discharge plume. Initially a dye flow rate of 64 ml/minute (~1 gal/hour) was injected but this rate did not yield significant fluorometer reading. Consequently the dye flow rate was sequentially increased to 126 ml/minute and finally to 252 ml/minute (~4 gal/hour).

Following the vertical profile fluorometery measurements, the pump intake was then located at a given depth and the system towed through the plume. The depth location of the pump intake was varied in order to locate the axis of the plume where the dye concentration was expected to be greatest. During both the vertical profile and tow measurements, range-range positioning measurements from both the OEC and survey vessel were continually obtained together with data on currents and the OEC heading.

The plume mapping task was completed in the late afternoon of April 11, 1981. The second phase of the plume survey involving the biological and water sampling program was performed on April 12, 1981. In order to provide a relatively constant plume sampling location relative to the discharge location, the survey vessel was moored to the stern of the OEC approximately 55m downstream from the discharge point. Furthermore in order to provide some assurance that samples were being obtained within the plume, dye injection was continued and monitored by the fluorometer system.

A series of 8 zooplankton tows were obtained both within and out of the plume. Since physically towing the zooplankton net continually within the plume was not practical due to the very limited size of the plume, it was decided to hold the vessel stationary and allow the current to flow through the net at a depth of 25m. Current speeds between 0.4 to 0.47m/sec were evident during these net tows. During each zooplankton tow the submersible pump was also attached just above the zooplankton net and a continuous recording of the fluorometer readings noted.

Following the plume zooplankton net tows the submerged pump was again lowered to 25m, the plume location confirmed, then the dye flow was stopped. Allowing about 10 minutes for the system to flush and recording no evidence of dye on the fluorometer, 9 individual water samples for each parameter were obtained representing samples within the plume.

At the completion of the in-plume water sampling operation, the pump intake was lowered to 45m to begin a vertical profile water sampling operation through the plume in 5m intervals to a water depth of 5m. This vertical sampling was performed between 1244-1330 HST.

Following the completion of the vertical profile water sampling operation, the survey vessel moved out of the plume and moved to the Sampson mooring line between the OEC and the surface buoy approximately 130m upstream of the mixed-water discharge port. This location represents the control station and identical zooplankton and water samples were obtained as described in the in-plume sampling operations.

The control station sampling program was completed at about 1830 hours and personnal and equipment associated with the plume survey were transferred from the OEC to the survey vessel, which then returned to Kawaihae Harbor.

III. PLUME MAPPING RESULTS

Appendix B describes the operational log and positioning data for the OEC during the entire plume survey. Appendix C describes the discharge flow conditions and environmental data during the plume survey. Note in Appendix C that the mixed-water flow rate is determined by the sum of the cold and warm water flow rates.

During the plume mapping survey discrete water samples were obtained onboard the OEC from the mixed-water discharge sampling port located between the mixed-water discharge pump and the hull discharging port. Table III.1 provides a listing of the discrete dye sample results and compares them to the calculated dye concentrations obtained by dividing the dye flow rate by the mixed-water discharge flow rate. Notice in Table III.1 that the fluorometer measured dye concentrations are significantly larger than the volume flow rate calculated values. A complete recheck of the fluorometer calibration was then carried out including a new set of diluted standards and the original calibration was confirmed. The dye pump flow rate was verified by integrating the total volume of dye injected as compared to the original volume of dye. By utilizng the elapse times shown in Appendix B together with Figure II.2 the calculated total volume of dye injected was 29.98 gallons. This corresponds very well with the estimated volume of 30 gallons of dye used (approximately 28 gallons from Argonne National Laboratory and about 2 gallons from the OEC).

Personal conversation with E-Tech personnel indicate that there is the possibility that the dye may not have mixed completely with the bulk flow and streams of higher dye concentration may exist even downstream from the mixed-discharge pump. Thus based on the available information the calculated mixed-water effluent dye concentrations have been selected as representative of the discharge flow.

Appendix D describes the current profile data obtained from a profiling current meter onboard the OEC during the plume survey. Both tabular and graphical data formats are shown in Appendix D. For interpretation of the plume survey results, Figure III.1 and III.2 describe the current speed and direction data at a depth of 25-30m during the entire survey period.

The vertical profile fluorometer data is shown in Appendix E where only profiles 3, 4, 5 and 6 are shown. Profiles 1 and 2 did not provide consistent data since the flow rate of dye was insufficient for reliable detection. Due to the limited size of the plume and the difficulty involved in maintaining a fixed survey vessel position relative to the discharge point at far distances from the discharge, vertical profiles were obtained only in the vicinity of the OEC where visual positioning with respect to the OEC could be maintained. Table III.2 presents a summary of the vertical profile result.

At this point a description of the vertical profile sampling operation would be fruitful. During a typical profile operation the sensor is lowered to a desired depth and a 60 second delay time is allowed to elapse representing the residence time of the system before the fluorometer record is annotated with the depth reading. Then the sensor is either lowered or raised in about

TABLE III.1

COMPARISON OF MIXED-WATER DISCHARGE
DISCRETE WATER SAMPLES VERSUS CALCULATED
DYE CONCENTRATIONS: April 11, 1981

Time (HST)	Discrete Dye Sample No.	Dye Pump Flow Rate (ml/min)	Dye Pump Flow Rate (GPM)	Mixed Discharge Flow (GPM)	Calculated[1] Dye Concentration (ppm)	Measured[2] Dye Concentration (ppm)
0815	1	0	0	153,050	0	N.D.[3]
0900	2	64	0.0169	153,050	0.11	0.20
1000	3	64	0.0169	152,350	0.11	0.18
1100	4	126	0.0333	155,480	0.21	0.39
1130	5	0	0	154,600	0	0.02
1200	6	0	0	154,600	0	N.D.
1300	7	252	0.0666	157,200	0.42	0.71
1400	8	252	0.0666	155,130	0.43	0.71
1500	9	252	0.0666	155,420	0.43	0.80
1600	10	252	0.0666	155,690	0.43	0.82
1700	11	252	0.0666	156,280	0.43	0.69
1800	12	0	0	157,190	0	0.01

[1]Dye Flow Rate/Mixed Discharge Flow Rate

[2]Concentration of Discrete Dye Sample Obtained at the Mixed-Water Sample Port Analyzed by the Turner Model III Fluorometer

[3]N.D. = Not Detectable

2-1/2m intervals to allow tie-straps securing the electrical power cable and water hose to the winch wire rope to be either secured or removed. These mid-interval strapping operations have not been annotated on the data records. Thus between any two depth intervals noted on the data records in Appendix E, the depth or thickness of the plume cannot be directly interpolated. Clearly if the plume dye signature occurs between two depth intervals, its thickness cannot be greater than the depth interval. Nevertheless linear interpolation is not suitable between depth intervals. Thus in Table III.2 the plume location and plume thickness have only been given in terms of depth intervals.

The recorded fluorometer data shown in Appendix E shows considerable variation in dye concentration through the plume. While this may possibly be indicative of streaking within the plume due to insufficient mixing, it may also be due to other possibilities. For example the plume thickness may only be 1-2m such that the vertical sinusoidal motion of the vessel could displace the pump intake in and out of the plume as represented in Profile No. 5.

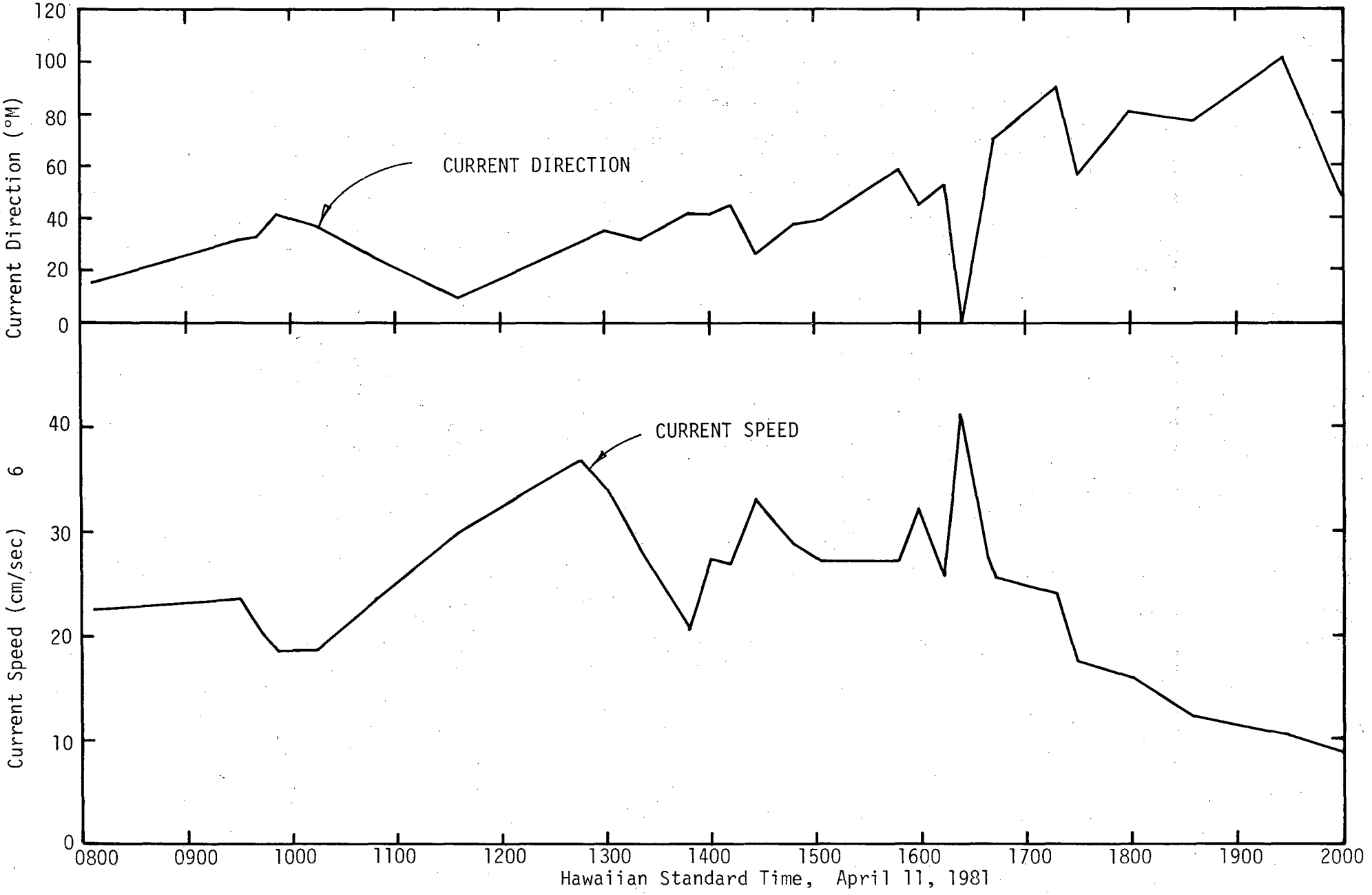


FIGURE III.1. CURRENT SPEED AND DIRECTION DATA FROM THE OEC AT A WATER DEPTH OF 25-30m, APRIL 11, 1981

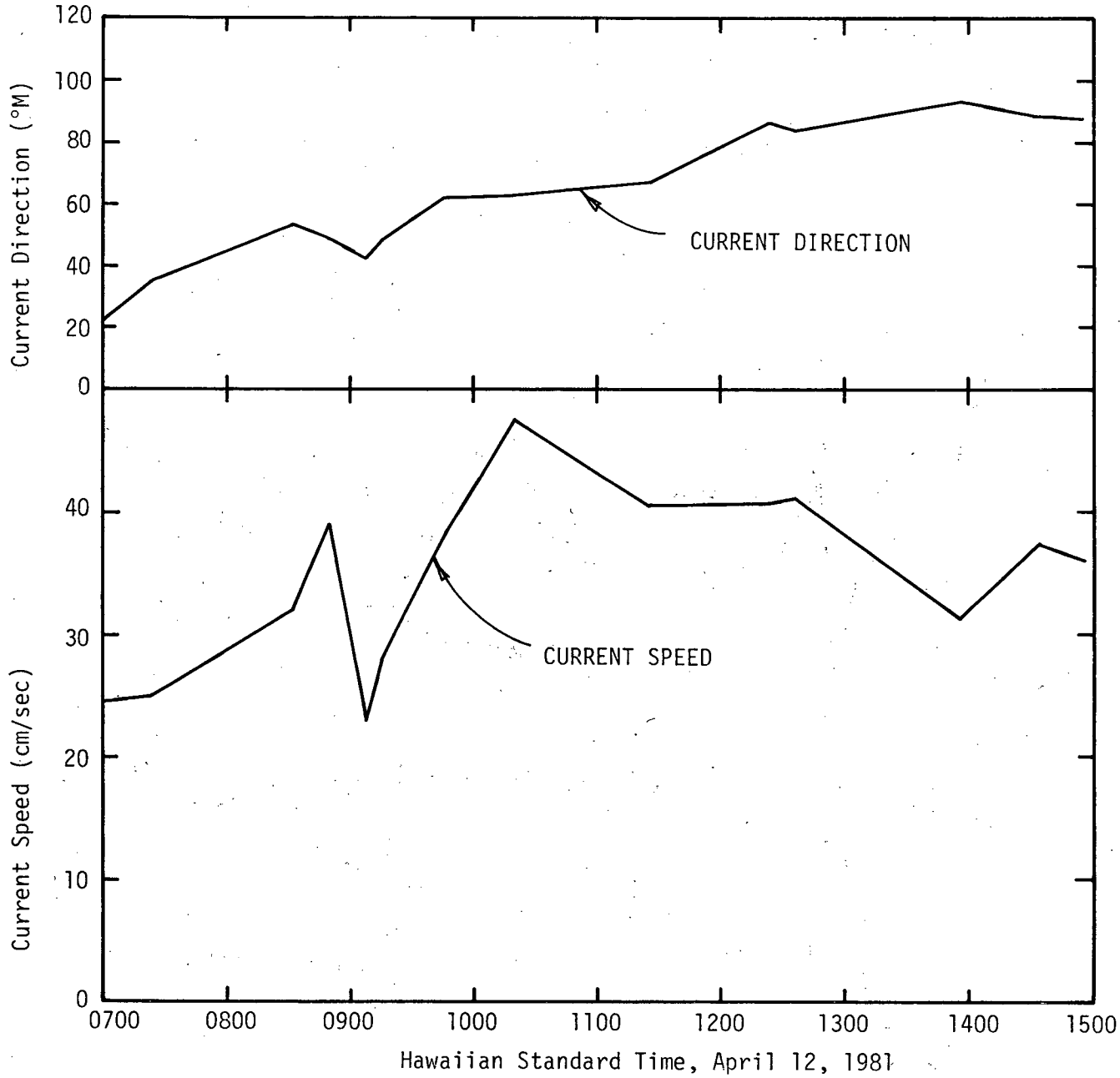


FIGURE III.2. CURRENT SPEED AND DIRECTION DATA FROM THE OEC AT A WATER DEPTH OF 25-30m, APRIL 12, 1981

TABLE III.2

SUMMARY OF PLUME SURVEY PROFILE DATA[1]

Profile No.	Distance From Discharge Location (m)	Maximum Dye Concentration (ppm)	Calculated Discharge Dye Concentration (ppm)	Dilution of Maximum Dye Concentration	Plume Vertical Location (m)	Plume Thickness (m)
4	23	0.035	0.424	12.2	20-25	< 5
5	45	0.043	0.429	10.0	30-35	< 5
6	36	0.042	0.429	10.2	25-30	~ 5

[1]See Appendix E for details

During the profile operation period Appendix C indicates that significant wave heights in the 1.1m range were evident. Also, there was difficulty in maintaining a consistent position within the plume for the entire vertical profiling operation. Thus the fluorometer results shown in Profile No. 6 may also include motions of the pump intake in and out of the plume due to vessel horizontal motions.

Appendix F describes the plume mapping fluorometer data while towing the submerged pump at constant depths and Table III.3 presents a summary of the two data results. In order to provide the results as shown in Table III.3 considerable vessel positioning data evaluation was necessary. While both the OEC and the survey vessel were provided with range-range electronic positioning systems, since both systems were independently calibrated over different ranges, the range-range values did not exactly agree when the position of both vessels relative to each other was known. Thus since the relative change of position of each system was assumed to be accurately represented, in order to determine the true distance from the OEC to the survey vessel, the survey vessel range-range readings were assumed to be correct and the OEC positioning data calibrated and adjusted to a consistent coordinate system. Typical distance corrections to the OEC data were +32m in the east direction (x) and -48m in the north direction (y).

Since the length scales of interest are in terms of meters, to facilitate data interpretation the latitude-longitude coordinate system was translated to an x,y coordinate system centered at latitude 19°50'N, longitude 156°15'W. Thus all following graphical and tabular displays reflect the x,y coordinate values.

During the plume mapping field operation phase, since the OEC was the only visual point of reference, all tows were conducted relative to the OEC's locations, as if the OEC maintained a stable position. Subsequent analysis of the positioning data as seen in Figure III.3 shows that the OEC moved

TABLE III.3

SUMMARY OF PLUME SURVEY TOW DATA[1]

Tow No.	Depth of Pump Intake (m)	Distance From Initial Discharge Location (m)	Distance Across Plume (m)	Dilution of Maximum Concentration	Maximum Dye Concentration (ppm)	Calculated Discharge Dye Concentration (ppm)
1	36	115	11	50	0.009	0.430
2	43	95	21	54	0.008	0.429
3	45	No Dye	Found			
4	35	290	99	75	0.006	0.429
5	39	No Dye	Found			
6	47	No Dye	Found			
7	29	140	96	16	0.026	0.426
8	29	90	44	14.2	0.030	0.426
9	29	75	57	16.6	0.026	0.426

[1]See Appendix F for data

considerably during the plume mapping survey. Consequently in order to locate the measured plume relative to the "initial" discharge location, the location of the plume was back integrated using the current vector until it intersected the locus of points representing the track of the mixed-water discharge port. Moreover adjustments in the x,y location of the plume due to the 60 sec. residence time of the pump system together with the position of the Trisponder antenna on the survey vessel and the distance of the pump intake behind the vessel during individual tows were incorporated to determine the plume-initial discharge relative locations. The results of this data reconstruction is shown in Figure III.4.

Notice in Figure III.4 that the x,y coordinate system is centered on the initial discharge location for each individual tow and the orientation of the OEC for each tow is also shown. From the results shown in Table III.3, Appendix F and Figure III.4, the plume axis is located at about 29m and is probably 5 to 10 meters in thickness.

Figure III.5 shows a graph of the dilution of the maximum recorded concentrations as a function of distance from the initial discharge for both the vertical profile and horizontal tow data. Also shown in Figure III.5 is a line representing the envelope of minimum dilution which may be representative of the centerline dilution of the effluent plume. Note that if the measured dye concentrations of the discrete samples obtained from the mixed-water discharge sampling port onboard the OEC had been assumed to represent the initial dye concentration, then the dilution values shown in Figure III.5 would be increased to about twice these values.

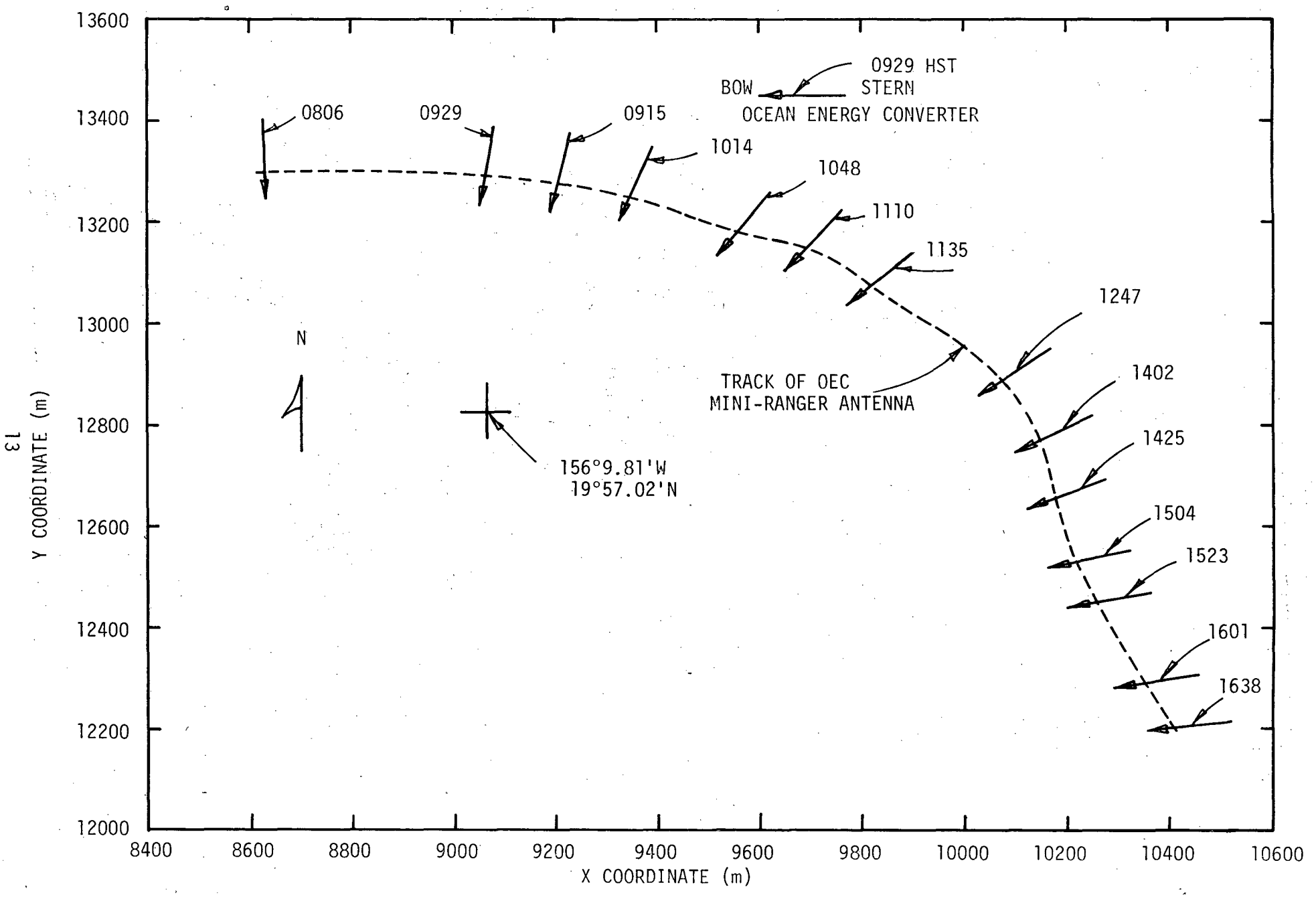


FIGURE III.3. TRACK OF THE OCEAN ENERGY CONVERTER DURING THE PLUME MAPPING SURVEY, APRIL 11, 1981

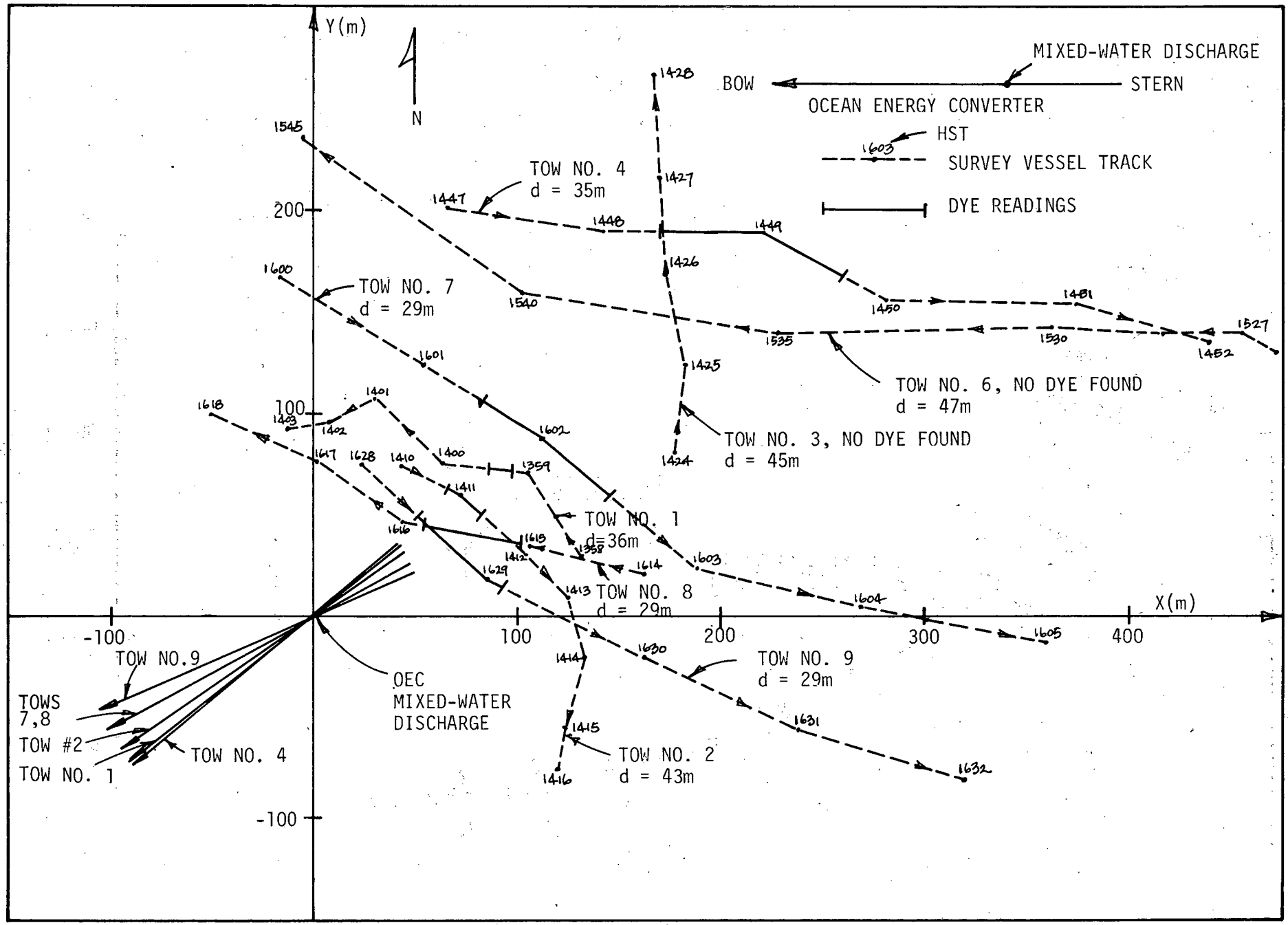


FIGURE III.4. SURVEY VESSEL TRACKS AND PLUME LOCATION DURING PLUME MAPPING TOWS, APRIL 11, 1981 RELATIVE TO THE INITIAL MIXED-WATER DISCHARGE LOCATION

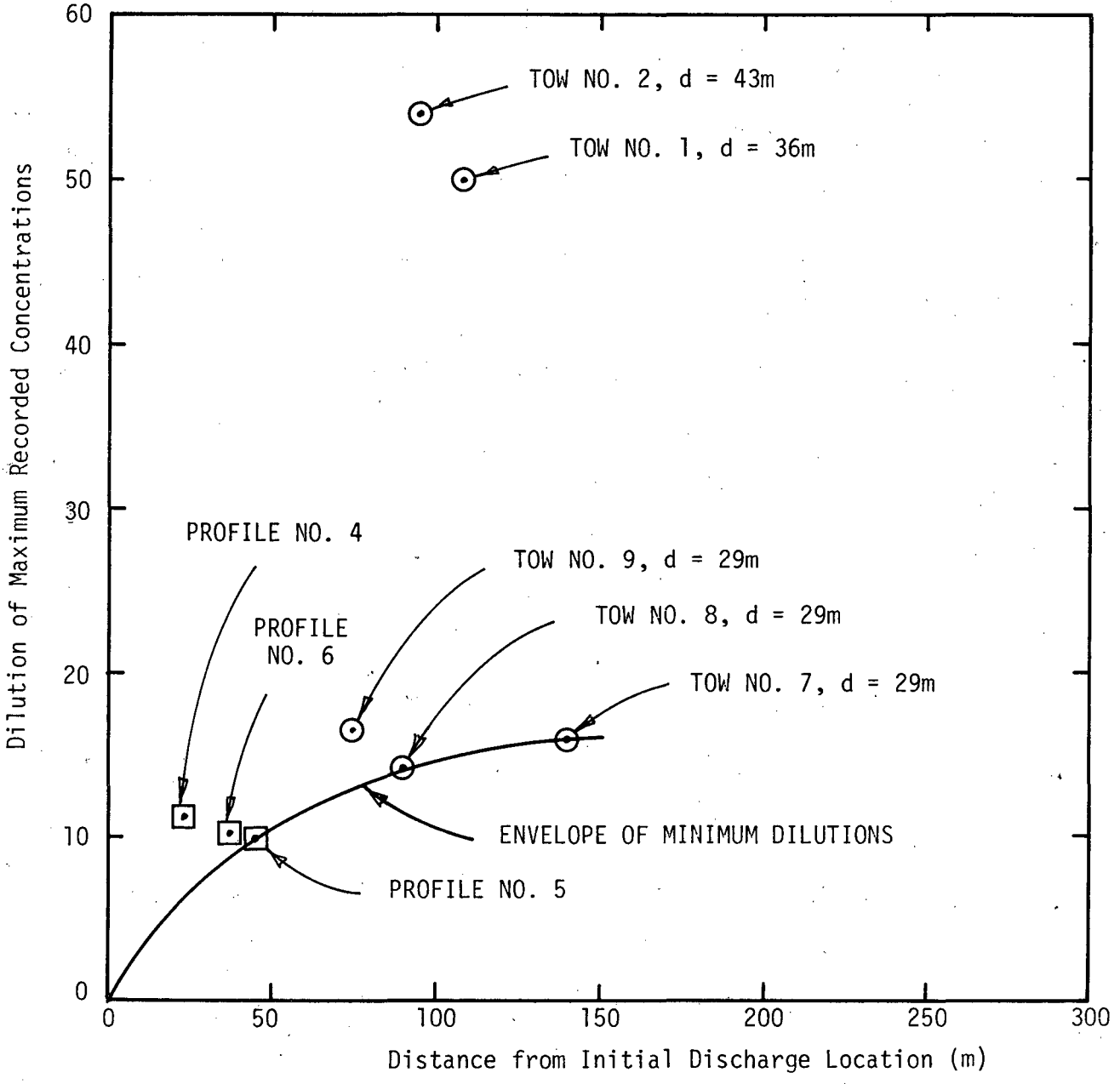


FIGURE III.5. DILUTIONS OF MAXIMUM RECORDED CONCENTRATION VERSUS DISTANCE FROM INITIAL DISCHARGE LOCATION

Figure III.6 describes the plume width versus distance from the initial discharge and shows a line representing the envelope of maximum plume width. Care should be used in representing this envelope of maximum plume widths as the size of the plume as a function of distance from the discharge, since this would only be true if the plume was crossed perpendicular to the plume flow axis.

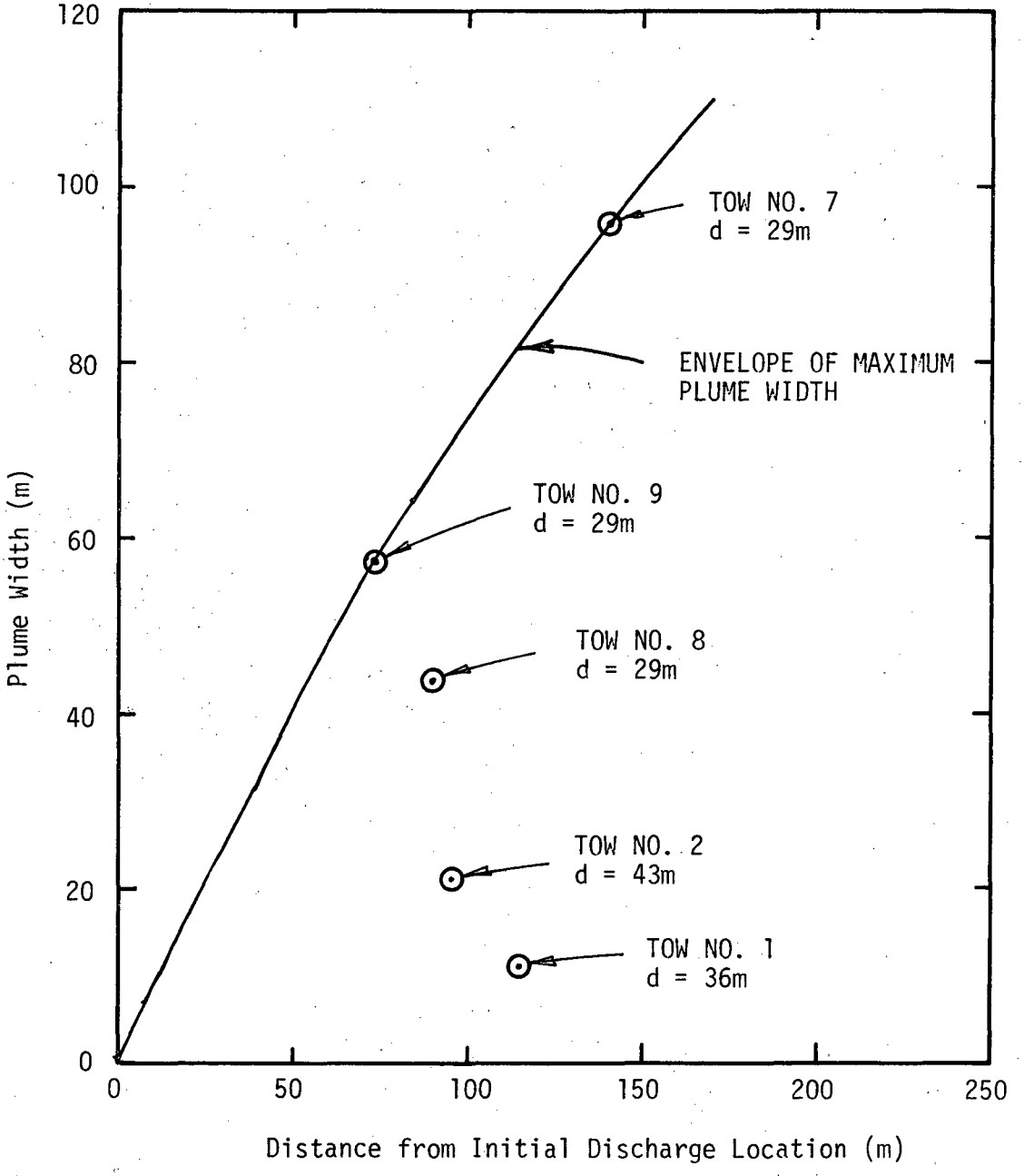


FIGURE III.6. PLUME WIDTH VERSUS DISTANCE FROM INITIAL DISCHARGE

IV. BIOLOGICAL AND WATER QUALITY RESULTS

IV.1. Chlorophyll, ATP and Phaeopigment

A. Comparison of 25-m Samples

Sets of multiple replicate samples were collected from 25m both within the OTEC-1 plume and at a control station. The mean (±SD) values for chlorophyll *a*, phaeopigments, P/C ratios, and ATP for both sample sets are given in Table IV.1; individual data for each replicate is given in Appendix G. Summary of the statistical comparisons of all parameters for the control vs. plume data is presented in Table IV.2.

Neither the chlorophyll *a*, phaeopigment or P/C data showed significant difference ($P > 0.05$) between the plume and control sets. The ATP data, assessing total microbial biomass, was significantly lower ($P < 0.001$) in the plume than at the control location. The mean ATP value in the plume (27.19 ± 9.56 ng·l^{-1}) was 61% of the mean found at the control station (44.54 ± 9.38 ng·l^{-1}).

Analysis of the ATP sample set from the plume environment is based on eleven replicates because of the exclusion of an anomalously high datum of 95.00 ng·l^{-1}. This value, which is more than three times the mean of the other replicates is believed to be due to the coincidental collection of a larger zooplankter; samples from these analyses were not pre-screened, and collection of a single copepod could result in the increase observed. A test was performed to verify the statistical validity of excluding this value from the sample set. The test is based upon calculation of the confidence interval about the mean of eleven replicates. Taking the most rigorous probability level ($P = 0.001$), the confidence interval (CI) about the mean ($\bar{x}$) is given by

$$CI = \bar{x} \pm t_{0.001} * S_{\bar{D}}$$

where $S_{\bar{D}}$ is the standard deviation divided by the square root of n; for d.f. = 10. This becomes

$$CI = \bar{x} \pm t_{0.001} * S_{\bar{D}}$$
$$= 27.19 \pm (4.587)\ (0.56/3.32)$$
$$= 27.19 \pm 13.22 \text{ ng·l}^{-1}$$

Addition of 13.22 to the mean (27.19) gives 40.41 ng·l^{-1}, which is less than half of the value which is the object of the test. Therefore, taking less than one change in 1000 of being wrong, it is valid to say that the 95.00 ng·l^{-1} value does not belong in the set, thus statistically verifying its exclusion.

B. Comparsion of Vertical Profiles

Sets of triplicate samples were collected at 5m intervals between 5 and 45m at a control station and within the OTEC-1 plume. The means (±SD)

TABLE IV.1

Summary of the mean values of pigments and ATP at 25 m. Control samples were taken near the OEC bow and plume samples were taken off the OEC stern as described in the Methods section. Nine replicate samples from 25 m, together with three samples taken at 25 m during profiling are compiled and the mean ($\bar{x}$), standard deviation (SD) and number of determinations (n) given. Data are given in units of $\mu g \cdot l^{-1}$ for chlorophyll *a* and phaeopigments, and in units of $ng \cdot l^{-1}$ for ATP; the P/C ratio is dimensionless.

Parameter	Control station $\bar{x}$ ±SD	n	Plume station $\bar{x}$ ± SD	n
chlorophyll *a* (C)	0.074 ± 0.018	12	0.069 ± 0.022	12
phaeopigments (P)	0.046 ± 0.036	12	0.052 ± 0.041	12
P/C ratio	0.622 ± 0.510	12	0.754 ± 0.641	12
ATP	44.54 ± 0.38	12	27.19 ± 9.56	11

TABLE IV.2

Summary of the statistical comparisons between data from the control station and the plume station. Analysis done using the Student's *t*-test; d.f. = degrees of freedom [= $(n_1 - 1) + (n_2 - 1)$], *P* = probability of a larger value. *** denotes significant differences at the 0.001 level.

	Comparison of Control vs. Plume Data		
Parameter	*t*	d.f.	*P*
chlorophyll *a* (C)	1.25	22	P > 0.20
phaeopigments (P)	1.20	22	P > 0.20
P/C	1.01	22	P > 0.20
ATP	96.39	21	P < 0.001***

for chlorophyll a, phaeopigments, P/C ratios, and ATP for both sample sets are given in Table IV.3; individual data for each replicate is given in Appendix G. The data for 25m represent the combination of triplicate samples from the profiling and nine replicates from the aforementions (Section IV.1.A) analyses. Vertical profiles of chlorophyll a, phaeopigment, P/C ratios and total microbial biomass (ATP) are presented in Figures IV.1 - IV.4, respectively. In all cases error bars on the figures represent the SD about the means.

For the pigment data, the vertical profiles for the control and plume stations are very similar and in most cases the SD about the means of each station overlap. Analysis of differences at each depth, via the t-test (d.f. = 4) indicate that the plume and control sets were not different ($P > 0.05$) at any depth; the ATP showed a significant ($P < 0.05$) difference only at 15 and 25m.

The data were also subject to chi-square analyses, inspecting the frequency with which the data from the plume station were less than those of the control station. For chlorophyll a and ATP the means of the plume data were less than those of the control in seven of nine instances, giving $\chi^2 = 2.778$; this value indicates insignificant differences in the frequency of the lower means at $P = 0.05$. This frequency is significant at the $P = 0.10$ level. The phaeopigment and P/C ratio data showed higher means in the plume in eight of nine instances; this represents a significantly ($P < 0.025$) greater frequency than would result from random chance.

C. Summary

The comparison of chlorophyll, phaeopigments and phaeopigment/chlorophyll ratios in the plume and at a control station at 25m depth showed no significant ($P > 0.05$) differences (t-test, d.f. = 20). A similar comparison of total microbial biomass (ATP) showed significantly ($P < 0.001$) lower ATP values in the plume than at the control station. The mean (±SD) ATP value in the plume (27.19 ± 9.56 ng·l^{-1}) was 61% of the mean at the control station (44.54 ± 0.38 ng·l^{-1}). Vertical profiles of all parameters were rather similar for the control and plume stations. Analysis of the differences in pigments at each depth (t-test) showed that the means at the control station were never different ($P > 0.05$) from the means at the plume station; similar analysis of ATP showed significant differences at 15 and 25m. Chi-square analysis indicated that the frequency of lower ATP and chlorophyll values in the plume at various depths was not different ($P > 0.05$) from what would be expected by random chance; the same analysis also showed a significantly ($P < 0.025$) higher frequency of phaeopigment and phaeopigment/chlorophyll ratios in the plume than at the control station.

TABLE IV.3

Summary of the numerical data from vertical profiles at a control station and within the OTEC-1 plume. The means (±SD) of triplicates are given for all depths except 25 m where n = 12. For all parameters, the data from which these means and SDs were calculated are given in Appendix G

Depth (m)	chlorophyll a (C) ($\mu g \cdot l^{-1}$)	Phaeopigment (P) ($\mu g \cdot l^{-1}$)	P/C	ATP ($ng \cdot l^{-1}$)
CONTROL STATION				
5	0.076 ± 0.027	0.043 ± 0.034	0.560 ± 0.483	57.30 ± 31.40
10	0.072 ± 0.017	0.053 ± 0.049	0.746 ± 0.694	41.46 ± 2.13
15	0.079 ± 0.028	0.060 ± 0.050	0.753 ± 0.684	46.04 ± 4.51
20	0.087 ± 0.009	0.025 ± 0.034	0.288 ± 0.392	41.11 ± 2.22
25	0.074 ± 0.018	0.046 ± 0.036	0.622 ± 0.510	44.54 ± 9.38
30	0.092 ± 0.000	0.036 ± 0.021	0.394 ± 0.236	79.46 ± 29.37
35	0.116 ± 0.029	0.289 ± 0.032	0.249 ± 0.280	47.97 ± 2.91
40	0.090 ± 0.015	0.066 ± 0.017	0.737 ± 0.218	48.32 ± 9.45
45	0.117 ± 0.047	0.047 ± 0.043	0.396 ± 0.401	64.33 ± 25.97
PLUME STATION				
5	0.072 ± 0.014	0.037 ± 0.036	0.520 ± 0.500	31.11 ± 6.55
10	0.066 ± 0.015	0.063 ± 0.041	0.967 ± 0.663	28.42 ± 4.46
15	0.073 ± 0.008	0.070 ± 0.024	0.958 ± 0.351	29.16 ± 2.74
20	0.072 ± 0.029	0.070 ± 0.040	0.980 ± 0.673	37.59 ± 14.50
25	0.069 ± 0.022	0.052 ± 0.041	0.754 ± 0.641	27.19 ± 9.56
30	0.105 ± 0.036	0.080 ± 0.052	0.757 ± 0.541	27.40 ± 7.56
35	0.099 ± 0.003	0.115 ± 0.052	1.155 ± 0.522	73.79 ± 52.93
40	0.093 ± 0.014	0.095 ± 0.013	1.019 ± 0.221	39.81 ± 0.32
45	0.107 ± 0.015	0.087 ± 0.077	0.813 ± 0.727	60.37 ± 28.25

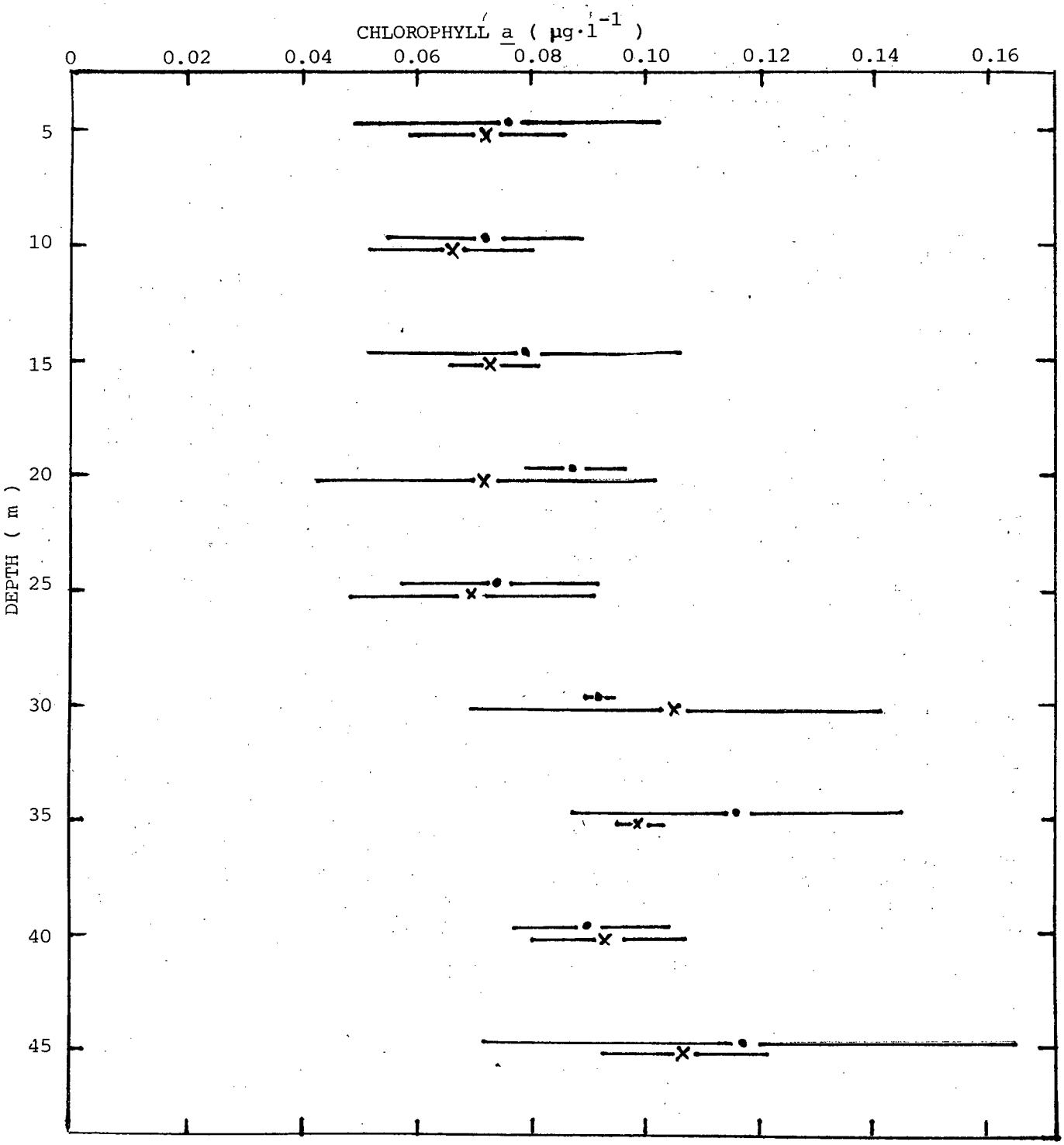


FIG. IV.1 Vertical profiles of chlorophyll a at a control station (●) and within the plume (x) of OTEC-1. Numerical date are given in Table 3 and Appendixes A and B. Error bars represent the standard deviation about the means of triplicates at all depths except 25 m when n = 12.

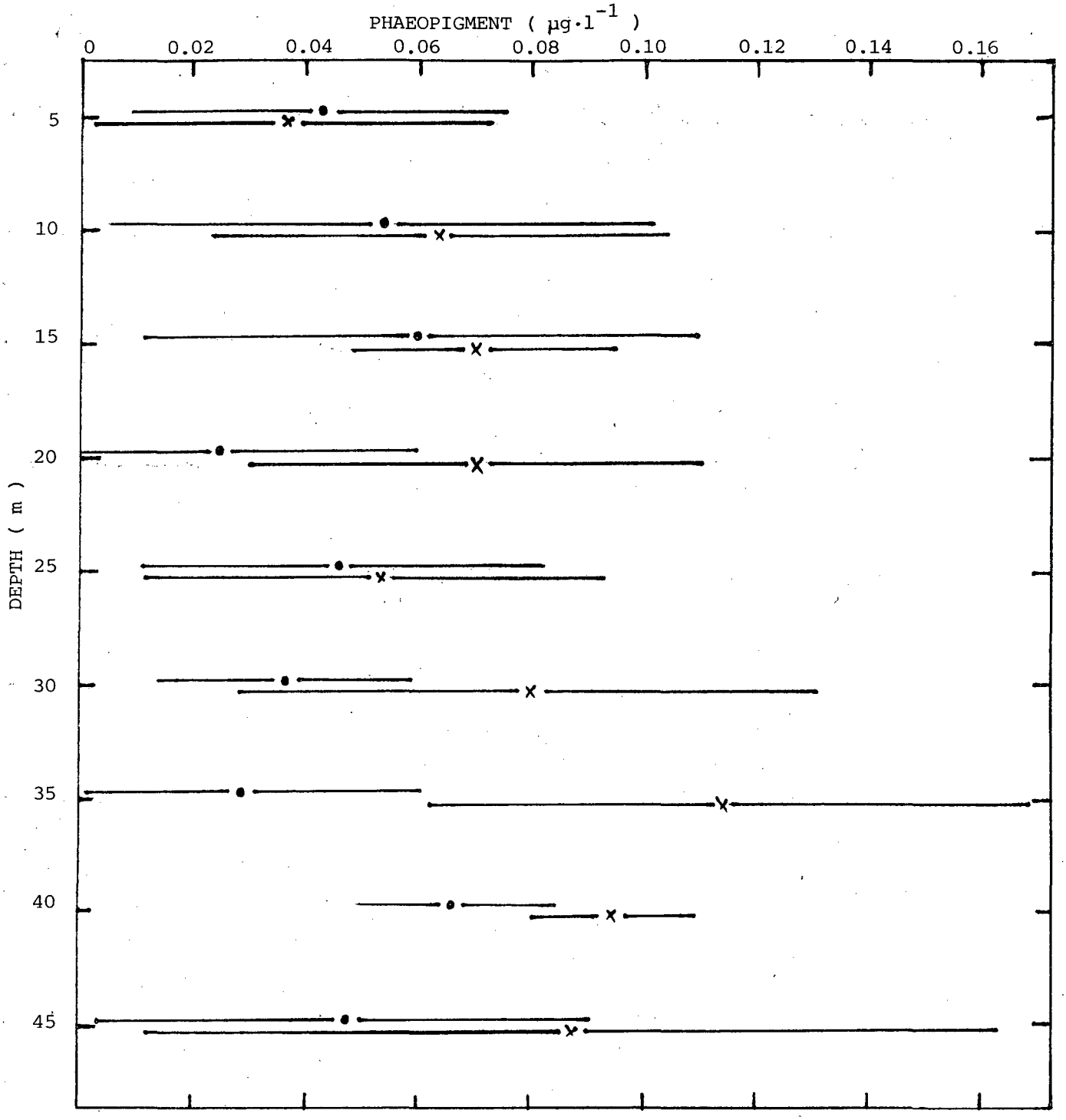


FIG. IV.2 Vertical profiles of phaeopigments at a control station (●) and within the OTEC-1 plume (x). Numerical data are given in Table 3 and Appendixes A and B. Error bars represent the standard deviation about the means of triplicates at all depths except 25 m where n = 12.

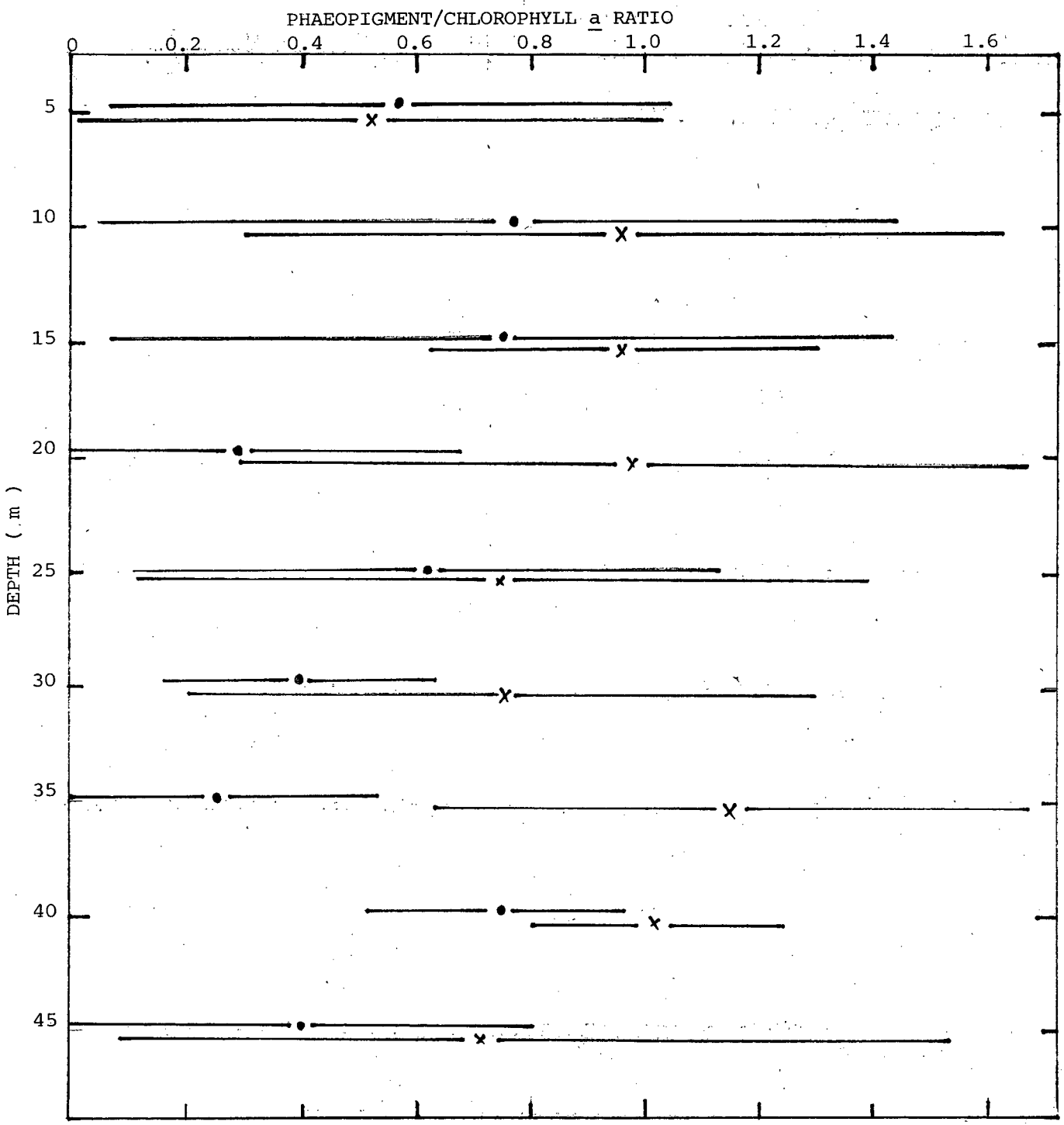


FIG. IV.3 Vertical profiles of phaeopigment/chlorophyll a ratios at a control station (●) and within the OTEC-1 plume (x). Numerical data are given in Table 3 and Appendixes A and B. Error bars represent the standard deviation about the means of triplicates at all depths except 25 m where n = 12. The SD values for all P/C ratios were calculated from the SD of P and C data via the equation

$$SD_{P/C} = \overline{P/C} * [(SD_P/\bar{P})^2 + (SD_C/\bar{C})^2]^{\frac{1}{2}}$$

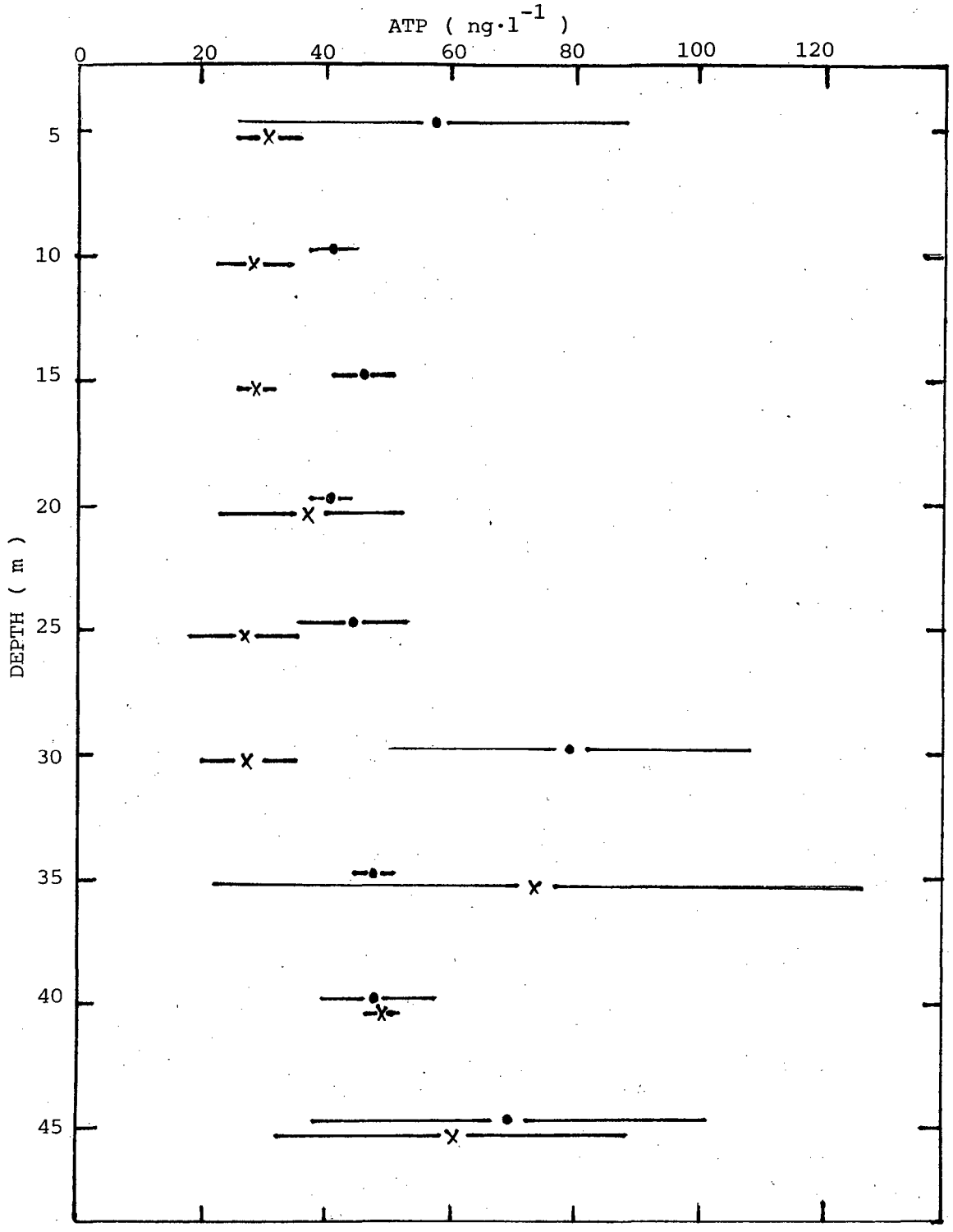


FIG. IV.4 Vertical profiles of ATP at a control station (o) and within the OTEC-1 plume (x). Numerical data given in Table 3 and Appendixes C and D. Error bars represent the standard deviation about the means of triplicates for all depths except 25 m where n = 11.

IV.2. Zooplankton Results

A. Plume Zooplankton Mortality Experiment

During the plume survey phase of the HOTEC-12 cruise, zooplankton samples were taken for determinations of mortality of animals in the plume. All zooplankton samples were obtained while the survey vessel M/V El Greco was moored to the OEC. For this specific experiment four samples were taken in the plume (Tow 1 to 4) as shown by the fluorometer records in Appendix H, and another four at a control station outside of the plume. The plume location during the zooplankton sampling was 55m downstream of the plume discharge while the control station was located about 150m upstream of the plume discharge port.

The samples were taken by attaching the net to the wire so that it could swing freely, then rapidly lowering the net to the sampling depth of 25m. The net was allowed to sample for at least 5 minutes during which time about 70-100m^3 of water was filtered. The net was then quickly raised, the cod end jar removed, and Neutral Red solution was added to the sample to provide a 1:200,000 dilution. The zooplankton were then incubated for 45 minutes, strained out of the water, preserved in 2% formalin in sea water and stored in a refrigerator.

Due to incomplete staining and apparent net mortality of small and fragile animals, only copepods in subsamples screened on a 500μm mesh were examined. Animals were considered alive if stain was visible in any part of their bodies. A minimum of 200 copepods of all taxonomic categories in the larger size fraction were counted. Also at least 200 or all animals in the sample of three species: *Euchaeta marina*, *Neocalanus robustior*, and *Corycaeus* sp. were counted.

Mortalities in the control (out-of-plume) samples ranged from 1.1% to 7.5% while those in the plume samples ranged from 0.5% to 21.6% as shown in Tables IV.4 and IV.5. Due to inhomogeneity of the variances, Fisher's exact probability test was used to test the hypothesis that plume mortalities exceeded the controls. For the data on all copepods (Table IV.4) the result was significant, $p = 0.014$. Since this result could be attributed to differences in species composition, the test was repeated for the three species selected (Table IV.5). The null hypothesis of no difference was rejected for *E. marina*, but not for *N. robustior*; the results for *Corycaeus* sp. were marginally significant.

To test the overall significance of the individual species' data a two-way factorial analysis of variance (ANOVA) was performed on the entire data set. The data was first transformed by arcsin ($\sqrt{P/100}$) to bring the variances closer to homogeneity. The ANOVA results (Table IV.6) show that there was indeed a significantly higher mortality in the plume ($p<.0025$), but no differences among the species.

The mortality rate of animals pumped through the plant was estimated in the following way. First mortalities in each plume sample due solely to the OTEC-1 operation was estimated, by subtracting the mean mortality in the control samples for each species (Table IV.7). Then the dilution of the plume was assessed from the fluorometer traces taken during each plume

sample. These dilution rates represent the dilution of total outflow in the ambient water. Since only about half of the outflow is from near-surface water, and since all three species are epiplanktonic, the dilution rates were doubled. These corrected rates were then multiplied by the corrected mortality values to provide estimates of mortality to those animals ingested in the warm water intake (Table IV.7). The mean mortality was 141%, with a 95% confidence interval of 70-212%. Thus the percent mortality cannot be distinguished from 100%, or total mortality to entrained animals. On the other hand, the high mortality suggests that animals may also be killed by impingment of the plume water as it exits the pipe.

Table IV.4

Live vs. dead determinations for all copepods in aliquots of samples taken in and out of the OTEC-1 plume

	Sample	Live	Dead	Total		% Dead
Out of Plume	1	250	20	270		7.4
	2	263	16	279		5.7
	3	253	17	270		6.3
	4	182	12	194		6.2
					$\bar{x}$	6.4
In Plume	1	185	19	204		9.3
	2	153	35	188		18.6
	3	162	21	183		11.5
	4	260	34	294		11.6
					$\bar{x}$	12.7

Test of hypothesis that the plume samples contained greater proportion dead than out of plume samples: $p = 0.014$, Fisher's exact probability test (used because of inhomogeneity of variances).

B. Zooplankton Abundance and Biomass

In addition to the mortality experiment samples, four in-plume and four control station zooplankton samples were obtained for biomass and numerical abundance assessment. The sampling technique was identical to the mortality sample acquisition. The acquired zooplankton samples were then split onboard, with 1/4 of the sample being filtered and the remainder preserved. Dry weights and ash-free dry weights were determined for the filtered material. Counts of aliquots of the preserved samples were

Table IV.5

Live vs. dead determinations for three species of copepod in aliquots of samples taken in and out of the OTEC-1 plume. P values determined by Fisher's exact probability.

		Live	Dead	Total	% Dead	Rank
Euchaeta marina						
Out of plume	1	210	12	222	5.4	2
	2	237	14	251	5.6	3
	3	225	10	235	4.3	1
	4	238	15	253	5.9	4
In plume	1	263	24	287	8.4	5
	2	76	21	97	21.6	8
	3	127	29	156	18.6	7
	4	158	17	175	9.7	6
					p = .014*	
Neocalanus robustior						
Out of plume	1	197	14	211	6.6	5
	2	179	2	181	1.1	2
	3	118	6	124	4.8	3
	4	161	10	171	5.8	4
In plume	1	205	1	206	0.5	1
	2	29	7	36	19.4	8
	3	33	4	37	10.8	6
	4	26	4	30	13.3	7
					p = 0.157	
Corycaeus sp.						
Out of plume	1	105	2	107	1.9	1
	2	49	4	53	7.5	6
	3	49	1	50	2.0	2
	4	98	3	101	3.0	3
In plume	1	217	12	229	5.2	5
	2	202	21	223	9.4	7
	3	229	11	240	4.6	4
	4	98	17	115	14.8	8
					p = 0.057	

TABLE IV.6

ANOVA table for live vs. dead determinations from Table IV.5. Percent live data are transformed by arcsin ($\sqrt{P/100}$) to normalize variance.

Source	Sum of Squares	DF	MS	F
Total	1240	23	-	
Cells	569.5	5	-	
Species	8.6	2	4.29	(NS)
Plume	462.9	1	462.9	12.425
Species x Plume	98.1	2	49.0	(NS)
Error	670.6	18	37.25	

Plume effect: $F = \frac{462.9}{37.25} = 12.425$

$F_{(1,18),\ (1\ tail,\ \alpha = .0025)} = 12.3$ Hence, $p < .0025$

TABLE IV.7

Estimates of total mortality of animals passing through OTEC-1 plant. (See text for explanation.)

Species	Sample	% Dead in plume	- Mean % dead out of plume	= Net	x Dilution	= % Killed
A)						
Euchaeta marina	PS1	8.4	5.3	3.1	22.5	70
	PS2	21.6	5.3	16.3	21.7	354
	PS3	18.6	5.3	13.3	22.0	293
	PS4	9.7	5.3	4.4	28.3	124
B)						
Neocalanus robustior	PS1	0.5	4.6	-4.1	22.5	-92
	PS2	19.4	4.6	14.8	21.7	321
	PS3	10.8	4.6	6.2	22.0	136
	PS4	13.3	4.6	8.7	28.3	246
C)						
Corycaeus sp.	PS1	5.2	3.6	1.6	22.5	36
	PS2	9.4	3.6	5.8	21.7	126
	PS3	4.6	3.6	1.0	22.0	22
	PS4	14.8	3.6	11.2	28.3	317
					$\bar{x}$	$S\bar{x}$
Mean % killed by passage thru plant (estimates)		A			210	67
		B			158	90
		C			125	68
Overall					163	41
95% confidence limits:					72	253

Significantly >0, but not different from 100%

performed with identification to the lowest taxonomic level practicable. The tow data sheets and count data for all plume survey samples are shown in Appendix I.

Table IV.8 shows the dry weight, ash-free dry weight, and percent ash of all samples both in and out of the plume. The in-plume samples had significantly lower biomass, both in dry weight and ash-free dry weight, and a significantly higher percent ash than samples at the control station outside of the plume.

There is no way of determining whether the differences in biomass were caused by the plume discharge, presence of the OTEC-1 platform itself, or patchiness. Nevertheless the differences in percent ash probably resulted from either the discharge operation or the presence of the platform. The samples themselves were quantitatively quite different; plume samples contained a great deal of detritus and micro-organisms bound in a matrix of mucus. The origin of this mucus is unknown. Plume samples also contained numerous hydroids and bryozoans which probably came from the hull of the OEC. These hydroids are a common shallow water species (W.J. Cooke, personal communication).

TABLE IV.8

Biomass measures of zooplankton samples obtained during the HOTEC-12 plume survey including statistical tests of difference between means

	Sample Number	Dry Weight (mg/m^3)	Ash-Free Dry Weight (mg/m^3)	Percent Ash (%)
In-Plume				
	PSB1	3.30	2.23	33
	PSB2	3.65	2.21	39
	PSB3	2.94	2.01	32
	PSB4	3.71	2.31	38
Mean	$\bar{X}_p$	3.40	2.19	35.5
Std Dev.	S_x	0.36	0.12	7.5
Out-of-Plume				
	OPB1	4.86	3.69	25
	OPB2	5.27	3.91	26
	OPB3	5.37	4.20	22
	OPB4	5.99	4.72	21
Mean	$\bar{X}_o$	5.37	4.12	23.5
Std Dev.	S_x	0.47	0.47	2.4
Statistical Tests				
$\bar{X}_o - \bar{X}_p$		1.97	1.93	-12
t_{bdf}		6.71	*	- 5.66
p (2 tailed)		< 0.001	0.014	< 0.01

*Variances were heterogeneous, P calculated by Fisher's exact probability test.

C. Zooplankton Count Data

Zooplankton count data from both in-plume and out-of-plume samples show little consistent variation. Table IV.9 describes the results of t tests of the differences in log abundance of common taxa of samples obtained in and out of the plume. Variances of the log abundance were homogeneous in all cases but for radiolaria. Note that the most common copepods, the calanoids, were much more abundant out of the plume than in it, which agrees with the biomass data.

TABLE IV.9

Results of t-tests for differences between means of abundances of common taxa in and out of the plume.

(N = 4 for each sample set)

Taxon	Means (No/100m^3) In-Plume	Out-of-Plume	t (Based on Logs)	P
Total Calanoid copepods	98	280	-11.5	0.0001
Acartia negligens	7.6	3.7	3.7	0.01
Clausocalanus sp.	19.7	90.6	- 8.0	0.0002
Euchaeta marina	3.3	12.5	- 4.5	0.004
Paracalanus sp.	1.5	2.7	- 1.3	0.2
Oithona sp.	15.0	21.9	- 0.6	0.5
Corycaeidae	16.2	10.3	2.0	0.09
Oncaea sp.	17.7	17.7	0.3	0.8
Foraminifera	13.9	5.7	3.8	0.009
Radiolaria	28.9	30.5	- 0.6	0.6
Gastropod veligers	2.0	7.6	- 4.4	0.005
Larvaceans	76	97	- 1.1	0.3
Chaetognaths	2.8	1.8	- 0.3	0.7
Fish eggs	110	144	0.04	~1

IV.3. Water Quality Data

A. Filtered Vs. Non-Filtered Nutrient Analyses

During the HOTEC-12 plume survey, due to onboard time constraints the nutrient samples were not filtered. During the previous HOTEC-11 cruise, since the nutrient samples were filtered, there was some question as to whether significant differences could be expected due to this factor. In order to answer this question special tests were performed which are described below.

Replicate nutrient samples from "in the plume" (#1-10) and "plume control" (#65-74) were analyzed using both unfiltered water and filtered water which was passed through a 10% HCl and distilled water rinsed Swinnex polypropylene filter holder and syringe using Whatman GF/C precombusted (500°C - 4 hr) filters. The filter - unfiltered sample pairs were analyzed right next to each other in all cases and all samples were analyzed within 30 minutes of exposure to air. The results of these tests (Tables IV.10 and IV.11) suggest that this method of filtering which is identical to the field technique used during the HOTEC-11 and all O'OTEC cruises can produce small increases in NH_4 ($\sim$0.02 μM) and Si ($\sim$0.2 μM). No other significant differences between filtered and unfiltered sample nutrients were evident. Additionally a filtered vs. non-filtered comparison was performed using the standard glass Millipore equipment (glass frit + glass funnel) on samples from HOTEC-12 (Site 1, Cast 1) (data not shown). Results from this test revealed considerable contamination of NH_4 ($\sim$0.5 μM) and Si ($\sim$1.5 μM). No other significant nutrient differences were evident. In the case of the Swinnex filtering the inclusion of particulates appears to have little effect on the total soluble phosphorus and nitrogen estimates, perhaps due to the relatively low (if not minute) particulate load. Due to the unknown and variable particulate effect (i.e. - any "other" water types with higher particle concentrations) on TSP and TSN estimates and the preference to obtain one discreet water sample for both nutrients and TSP - TSN (for good inorganic - organic comparisons), it appears Swinnex field filtering will provide the cleanest water processing for nutrient analyses. If inorganic nutrients alone are desired and if the sample water has low particulates then unfiltered sample collection would be preferred.

B. Plume Nutrients and Dissolved Oxygen Results

Tables IV.12 and IV.13 show the plume replicate averages and individual data is shown in Appendix J. In Tables IV.12 and IV.13 the following describe the physical situation:

Samples 1-10:	In-plume replicates 55m downstream from the discharge at a water depth of 25m.
Samples 65-74:	Out-of-the-plume control station replicates 75m upstream of the discharge at a water depth of 25m.
Samples 11-37:	Triplicate "through the plume" profile between 5-45 meters at 55m downstream of the discharge.
Samples 38-64:	Triplicate "out-of-the-plume" profile between 5-45 meters at 75m upstream of the discharge.

TABLE IV.10

HOTEC-12: Plume Study (Nutrients) 04-12-81
In Plume Replicates (25 m depth) (Filtered vs. Non-Filtered)
(in ug-at/liter)

Sample	PO_4	NO_3 + NO_2	NH_4	Si	Total Soluble Phosphorus	Total Soluble Nitrogen
1	0.214	0.725	0.545	3.04	0.367	4.70
1F	0.214	0.725	0.589	3.42	0.367	5.02
2	0.168	0.622	0.523	2.66	0.367	4.31
2F	0.184	0.622	0.545	2.66	0.367	4.36
3	0.184	0.622	0.523	2.47	0.383	4.77
3F	0.199	0.673	0.523	2.85	0.367	4.39
4	0.214	1.04	0.523	3.23	0.413	5.07
4F	0.214	1.04	0.545	3.99	0.383	4.78
5	0.230	1.30	0.545	3.99	0.444	5.96
5F	0.214	1.30	0.523	4.18	0.428	6.00
6	0.184	0.829	0.480	2.66	0.398	5.58
6F	0.184	0.881	0.523	3.23	0.383	5.64
7	0.214	1.35	0.501	3.99	0.413	6.29
7F	0.214	1.35	0.501	3.99	0.428	6.02
8	0.168	0.622	-	2.47	0.383	4.93
8F	0.168	0.622	-	2.47	0.383	5.09
9	0.153	0.518	-	2.09	0.398	5.81
9F	0.153	0.518	-	2.09	0.367	5.73
10	0.153	0.881	-	2.66	0.367	5.53
10F	0.168	0.881	-	2.66	0.367	5.44
Filtered - Non Filtered: (Mean ± standard deviation)						
$\bar{x}$ (µm)	0.003	0.010	0.016	0.23	-0.009	-0.05
± Sx	0.010	0.022	0.024	0.28	0.015	0.22

Notes: "F" - denotes sample filtered through precombusted Whatman GF/C filters using 10% HCℓ and distilled water rinsed plastic Swinnex(R) holder and syringe.

TABLE IV.11

HOTEC-12: Plume Study (Nutrients) 04-12-81
Plume Control Replicates (25 m depth) (Filtered vs. Non Filtered)
(in ug-at/liter)

Sample	PO_4	NO_3 + NO_2	NH_4	Si	Total Soluble Phosphorus	Total Soluble Nitrogen
65	0.188	0.060	0.426	1.51	0.361	3.35
65F	0.204	0.060	0.469	1.89	0.361	4.09
66	0.188	0.060	0.405	1.51	0.361	4.13
66F	0.188	0.060	0.447	1.89	0.361	4.03
67	0.188	0.060	0.447	1.70	0.377	4.30
67F	0.157	0.060	0.447	1.70	0.361	3.93
68	0.173	0.060	0.426	1.51	0.361	4.11
68F	0.157	0.060	0.426	1.70	0.361	4.08
69	0.157	0.060	0.426	1.51	0.361	4.17
69F	0.157	0.060	0.426	1.51	0.361	4.75
70	0.157	0.060	0.426	1.51	0.393	5.17
70F	0.157	0.060	0.426	1.51	0.393	5.31
71	0.141	0.120	0.362	2.26	0.346	4.69
71F	0.141	0.090	0.362	2.45	0.330	4.60
72	0.141	0.060	0.405	1.70	0.393	5.14
72F	0.141	0.060	0.405	1.70	0.377	5.42
73	0.141	0.060	0.405	1.32	0.377	5.32
73F	0.141	0.060	0.405	1.51	0.377	4.92
74	0.141	0.060	0.405	1.51	0.361	4.57
74F	0.141	0.060	0.405	1.51	0.361	4.23
Filtered - Non Filtered: (Mean ± standard deviation)						
$\bar{x}$ (µm)	-0.003	-0.003	0.009	0.13	-0.005	0.04
± Sx	0.012	0.009	0.018	0.16	0.008	0.39

Notes: "F" - denotes sample filtered through precombusted Whatman GF/C filters using 10% HCℓ and distilled water rinsed plastic Sinnex(R) holder and syringe.

TABLE IV.12

HOTEC-12: Plume Study (Nutrient Averages) 04-12-81
(mean ± standard deviation in ug-at/liter)
*All analyses on unfiltered seawater.

Samples	Depth (m)	PO_4	$NO_3 + NO_2$	NH_4	Si	Total Soluble Phosphorus	Total Soluble Nitrogen
1-10	25	0.19 ± 0.03	0.85 ± 0.29	0.52 ± 0.02	2.93 ± 0.64	0.39 ± 0.03	5.30 ± 0.63
65-74	25	0.16 ± 0.02	0.07 ± 0.02	0.41 ± 0.02	1.60 ± 0.25	0.37 ± 0.02	4.50 ± 0.61
11-13	5	0.14 ± 0.00	0.08 ± 0.03	0.52 ± 0.03	1.58 ± 0.11	0.39 ± 0.01	3.99 ± 0.17
14-16	10	0.14 ± 0.01	0.14 ± 0.03	0.52 ± 0.00	2.09 ± 0.50	0.39 ± 0.00	4.17 ± 0.07
17-19	15	0.13 ± 0.04	0.49 ± 0.03	0.45 ± 0.10	2.09 ± 0.33	0.37 ± 0.06	4.41 ± 0.23
20-22	20	0.16 ± 0.01	0.57 ± 0.14	0.52 ± 0.03	2.41 ± 0.29	0.42 ± 0.02	5.46 ± 0.18
23-25	25	0.17 ± 0.00	0.66 ± 0.08	0.47 ± 0.01	2.60 ± 0.11	0.42 ± 0.00	5.46 ± 0.17
26-28	30	0.13 ± 0.04	0.26 ± 0.27	0.46 ± 0.06	1.96 ± 0.44	0.38 ± 0.07	5.17 ± 0.41
29-31	35	0.15 ± 0.00	0.10 ± 0.00	0.52 ± 0.00	1.71 ± 0.00	0.43 ± 0.06	3.58 ± 0.90
32-34	40	0.15 ± 0.01	0.10 ± 0.00	0.52 ± 0.00	1.58 ± 0.22	0.40 ± 0.00	3.50 ± 0.17
35-37	45	0.14 ± 0.01	0.10 ± 0.00	0.49 ± 0.01	1.58 ± 0.11	0.38 ± 0.01	3.94 ± 0.39
38-40	5	0.14 ± 0.01	0.10 ± 0.00	0.46 ± 0.00	1.58 ± 0.29	0.39 ± 0.00	4.41 ± 0.33
41-43	10	0.14 ± 0.00	0.10 ± 0.00	0.47 ± 0.02	1.33 ± 0.00	0.39 ± 0.00	4.91 ± 0.21
44-46	15	0.15 ± 0.01	0.07 ± 0.03	0.50 ± 0.02	1.33 ± 0.00	0.37 ± 0.00	5.02 ± 0.61
47-49	20	0.13 ± 0.01	0.07 ± 0.03	0.47 ± 0.02	1.64 ± 0.11	0.39 ± 0.00	4.61 ± 0.13
50-52	25	0.12 ± 0.00	0.05 ± 0.00	0.50 ± 0.00	1.64 ± 0.11	0.35 ± 0.01	3.58 ± 0.50
53-55	30	0.11 ± 0.02	0.08 ± 0.03	0.52 ± 0.05	1.89 ± 0.50	0.33 ± 0.05	4.41 ± 0.58
56-58	35	0.12 ± 0.05	0.10 ± 0.00	0.48 ± 0.15	2.33 ± 1.33	0.34 ± 0.08	4.14 ± 0.30
59*61	40	0.17 ± 0.02	0.08 ± 0.04	0.61 ± 0.03	2.08 ± 0.26	0.39 ± 0.00	4.69 ± 0.21
62-64	45	0.14 ± 0.05	0.12 ± 0.03	0.57 ± 0.10	1.95 ± 0.43	0.31 ± 0.11	4.21 ± 0.58

Notes: *#60 excluded (contaminated)
1) Samples #1-10 = "In Plume Replicates" - Only 7 NH_4 analyses.
2) Samples #65-74 = "Plume Control Replicates".
3) Samples #11-37 = "In the Plume" depth profiles.
4) Samples #38-64 = "Plume Control" depth profiles.

TABLE IV.13

HOTEC-12: Plume Study 04-12-81
Dissolved Oxygen (mℓ/ℓ)

	Sample	Diss. O_2 mℓ/ℓ	$\bar{x} \pm Sx$		Sample	Diss. O_2 mℓ/ℓ	$\bar{x} \pm Sx$
"In Plume"	#1	5.370			#38	5.089	
	2	5.382		5 m	39	5.038	5.068
	3	5.370			40	5.076	± 0.027
	4	5.370			41	4.987	
	5	5.297		10 m	42	5.013	5.000
	6	5.357			43	5.000	± 0.013
	7	5.344			44	5.025	
	8	5.446		15 m	45	5.000	5.042
	9	5.293	5.352		46	5.102	± 0.053
	10	5.293	± 0.048		47	5.115	
	11	5.306		20 m	48	4.885	4.974
5m	12	5.153	5.238		49	4.923	± 0.123
	13	5.255	± 0.078		50	4.974	
	14	5.306		25 m	51	4.974	5.008
10m	15	5.178	5.191		52	5.076	± 0.059
	16	5.089	± 0.109		53	5.038	
	17	5.268		30 m	54	5.038	5.030
15m	18	5.153	5.221		55	5.013	± 0.014
	19	5.242	± 0.060		56	4.910	
	20	5.229		35 m	57	5.000	4.944
20m	21	5.293	5.250		58	4.923	± 0.049
	22	5.229	± 0.037		59	5.051	
	23	5.293		40 m	60	5.000	5.013
25m	24	5.306	5.276		61	4.987	± 0.034
	25	5.229	± 0.041		62	4.987	
	26	5.242		45 m	63	4.987	4.970
30m	27	5.331	5.293		64	4.936	± 0.029
	28	5.306	± 0.046		65	5.076	
	29	5.191			66	5.102	
35m	30	5.293	5.178		67	5.025	
	31	5.051	± 0.122		68	5.013	
	32	5.191			69	5.102	
40m	33	5.280	5.242		70	5.115	
	34	5.255	± 0.046		71	5.140	
	35	5.293			72	5.102	
45m	36	5.255	5.268		73	5.153	5.074
	37	5.255	± 0.022		74	4.911	± 0.073

"Plume Control"

There were significantly higher NO_3 and* NO_2 (by ∿0.8 μM) and Si (by ∿1.3 μM) concentrations in the plume compared to the ambient out of the plume waters. The mean orthophosphate concentrations appear slightly higher (+ 0.03 μM) in the plume, however, this difference does not appear significant. After correcting the total soluble nitrogen and phosphorus estimates for their corresponding inorganic nitrogen and phosphate concentrations, it appears that there is no significant "in vs. out of the plume" differences in either dissolved organic phosphorus (DOP) or dissolved organic nitrogen (DON). DOP concentrations appear to be ∿0.25 ± 0.04 μM throughout the water column, while DON concentrations although much more variable appear to be ∿3.6 ± 0.7 μM throughout. DON values may appear slightly higher at 25m in the plume; however, poor statistics on DON estimates will tend to overshadow this apparent difference.

The plume effects of elevated NO_3 and* NO_2 and Si concentrations also appear to be quite evident in the "through the plume" depth profile (samples #11-37). This profile shows an obvious peak at the 25 meter depth where the highest NO_3 and* NO_2 and Si concentrations are seen at the ∿0.7 μM-N and ∿2.6 μM-Si levels respectively. Above ambient levels of NO_3 and NO_2, Si, and to some extent PO_4 are seen between 10-30 meters while normal (ambient) low levels are seen below 30 meters. Dissolved oxygen as well as ammonium concentrations appear significantly higher in the plume when compared to the plume control waters; however, the depth profile through the plume does not show such a trend. Aeration of the plume waters from pumping and mixing may be a controlling factor here.

*NO_3 and NO_2 = is almost all NO_3 - nitrate (<0.02 μM-NO_2)

OTEC-1 PLUME SURVEY

APPENDIX A

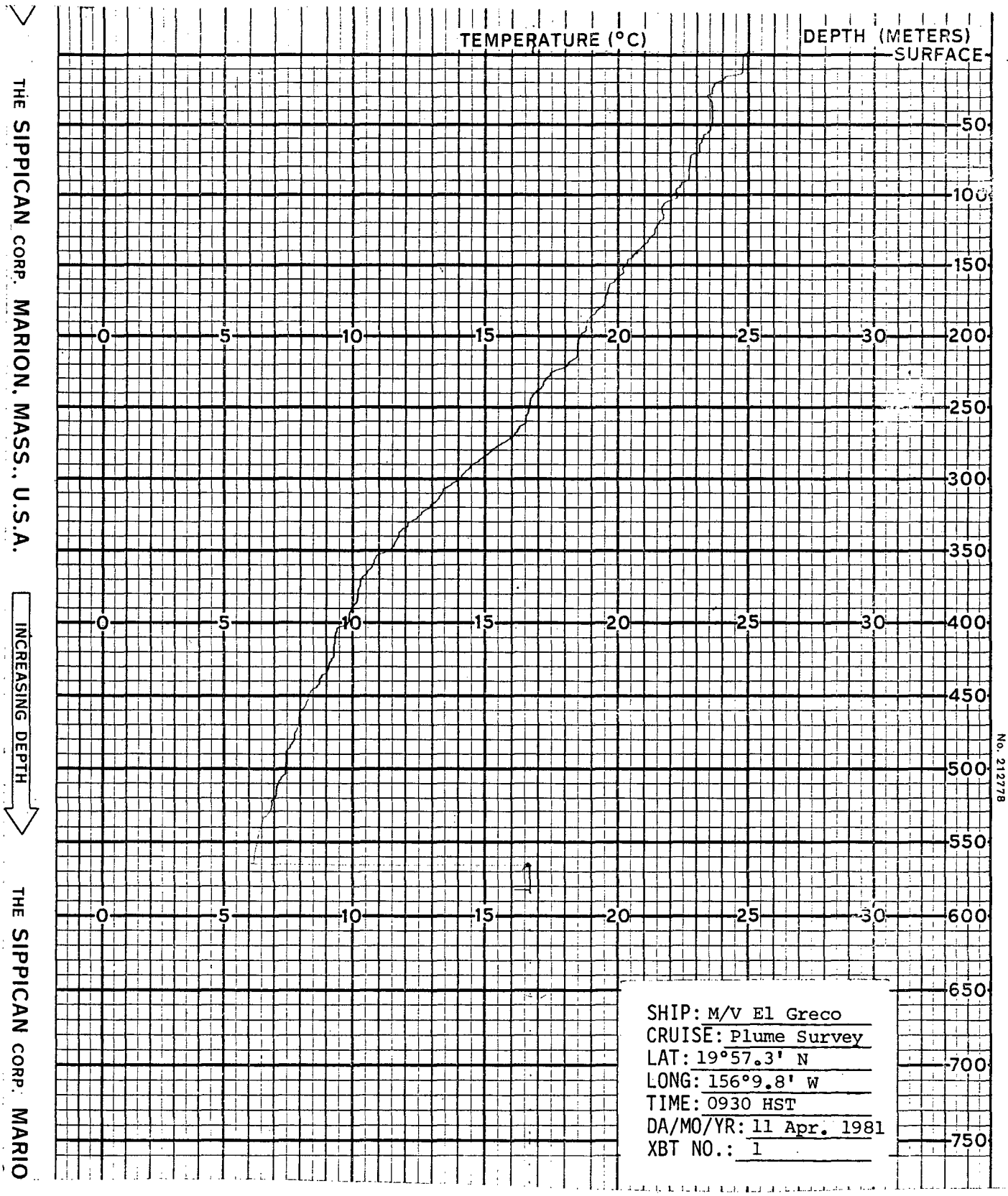
XBT DATA

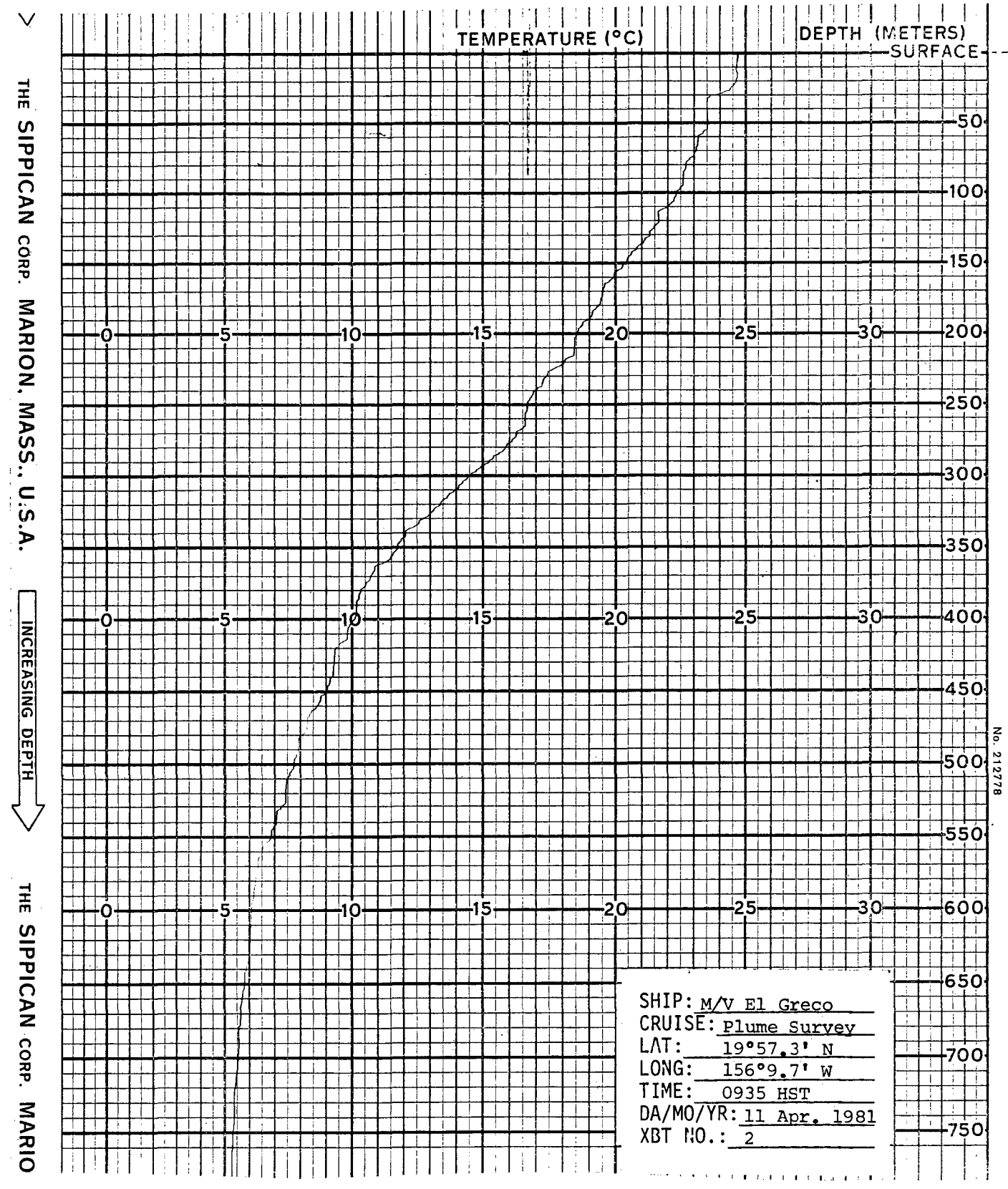
TABLE A1

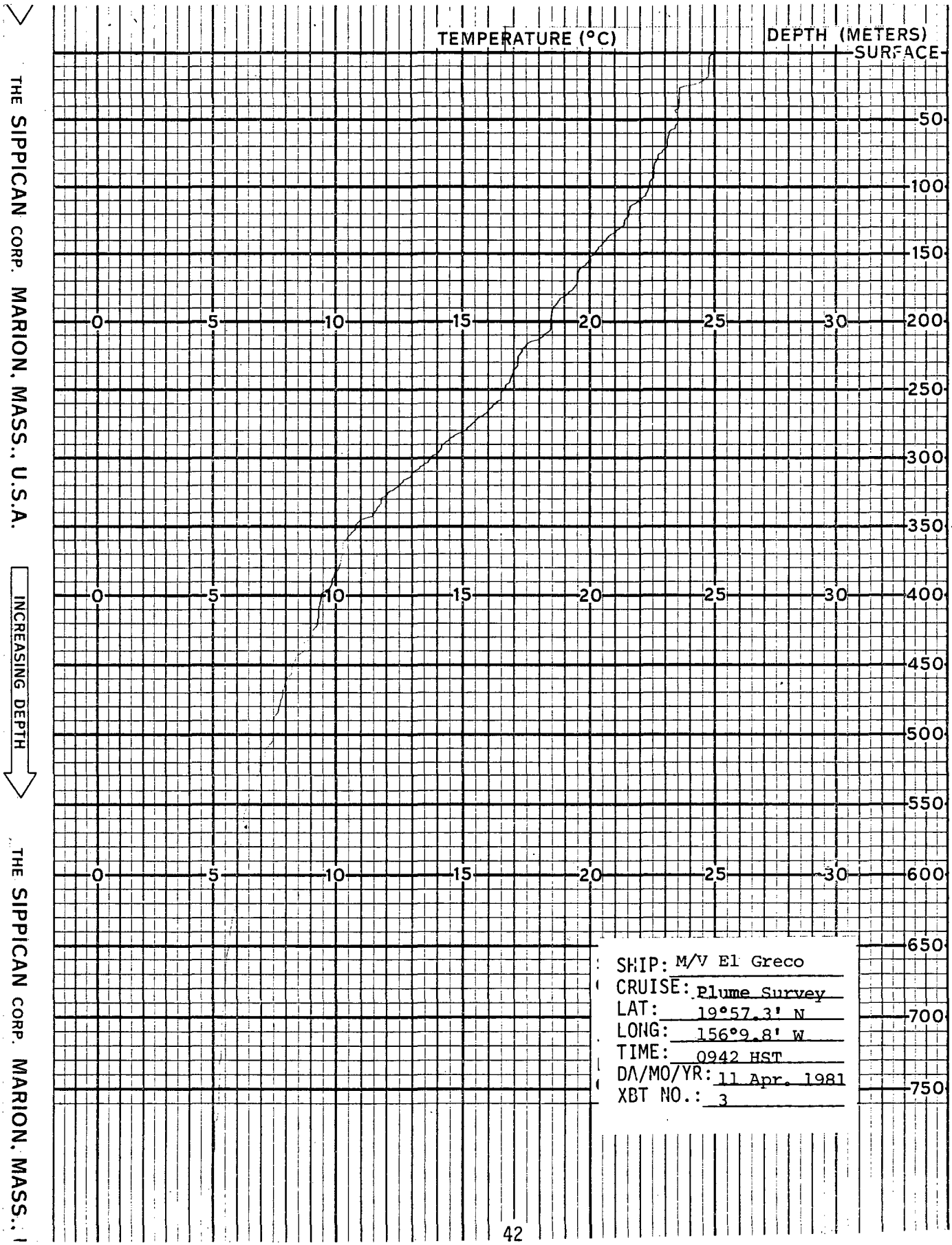
XBT LOG

Cruise: HOTEC-12 Plume Survey Vessel: M/V El Greco

XBT No.	Date	Time (HST)	Lat. (N)	Long. (W)	x (m)	y (m)	Comments
1	11 April 1981	0930	19°57.3'	156°9.8'	9,095	13,411	In-plume 3m downstream from Discharge Point
2	11 April 1981	0935	19°57.3'	156°9.7'	9,195	13,368	Outside of Plume
3	11 April 1981	0942	19°57.3'	156°9.8'	9,128	13,458	In-plume at 45m downstream of Discharge
4	11 April 1981	1130	19°57.2'	156°9.2'	10,041	13,198	Directly off OEC stern 50m from Discharge
5	11 April 1981	1318	19°57.0'	156°9.1'	10,208	12,892	During Profile No. 5
6	12 April 1981	0945	19°56.7'	156°9.1'	10,383	12,363	Directly off OEC stern 50m from Discharge
7	12 April 1981	1132	19°56.5'	156°9.0'	10,448	11,968	Directly off OEC stern 50m from Discharge
8	12 April 1981	1606	19°55.9'	156°9.1'	10,358	10,787	Port side of OEC at Control Station


TEMPERATURE (°C)
DEPTH (METERS)
SURFACE
50
100
150
0
5
10
15
20
25
30
200
250
300
350
400
450
500
550
600
650
700
750
SHIP: M/V El Greco
CRUISE: Plume Survey
LAT: 19°57.3' N
LONG: 156°9.8' W
TIME: 0930 HST
DA/MO/YR: 11 Apr. 1981
XBT NO.: 1
THE SIPPICAN CORP. MARION, MASS., U.S.A.
INCREASING DEPTH
THE SIPPICAN CORP. MARION
No. 212778


TEMPERATURE (°C)
DEPTH (METERS)
SURFACE
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
0
5
10
15
20
25
30
SHIP: M/V El Greco
CRUISE: Plume Survey
LAT: 19°57.3' N
LONG: 156°9.7' W
TIME: 0935 HST
DA/MO/YR: 11 Apr. 1981
XBT NO.: 2
THE SIPPICAN CORP. MARION, MASS., U.S.A.
INCREASING DEPTH
THE SIPPICAN CORP. MARIO
No. 212778

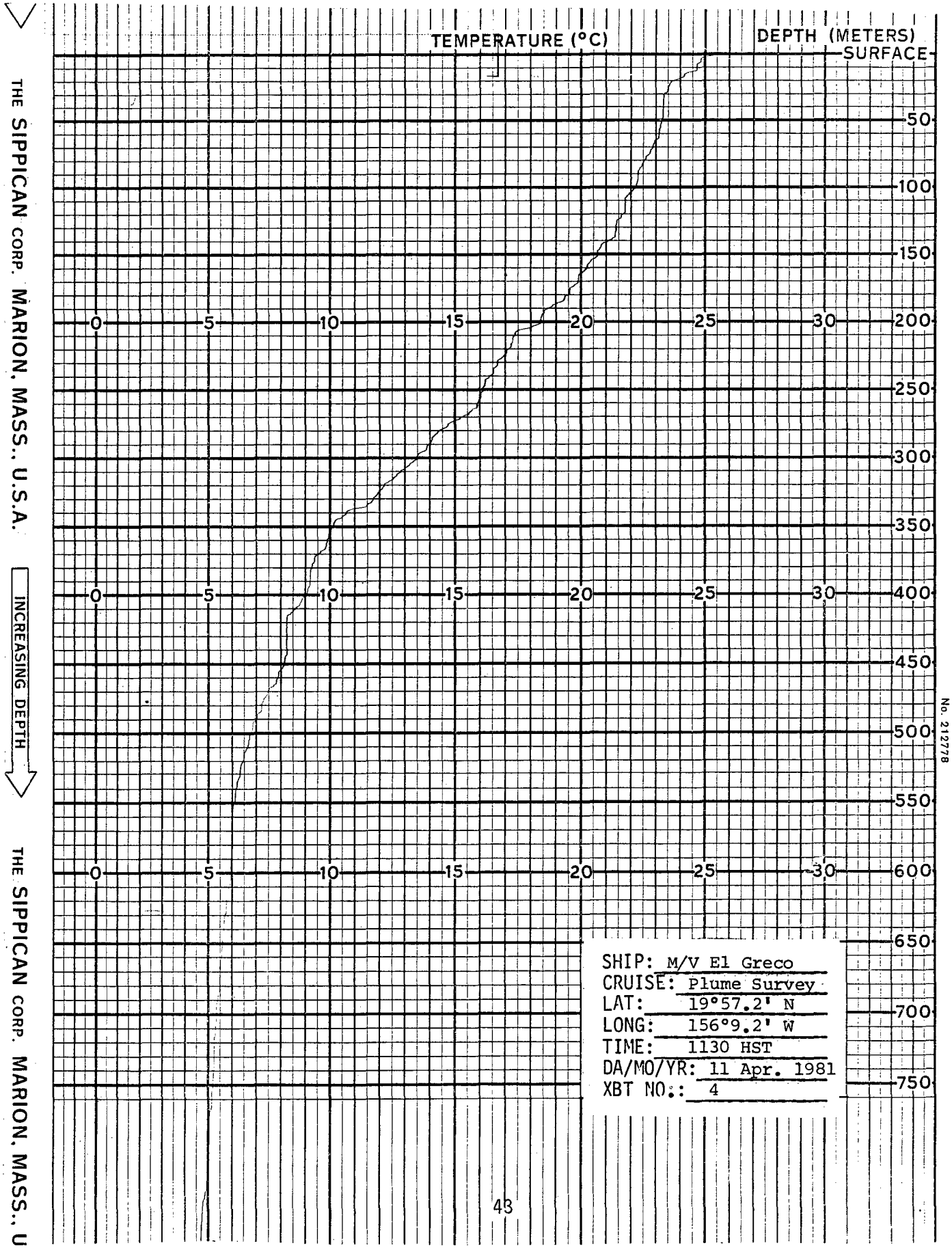


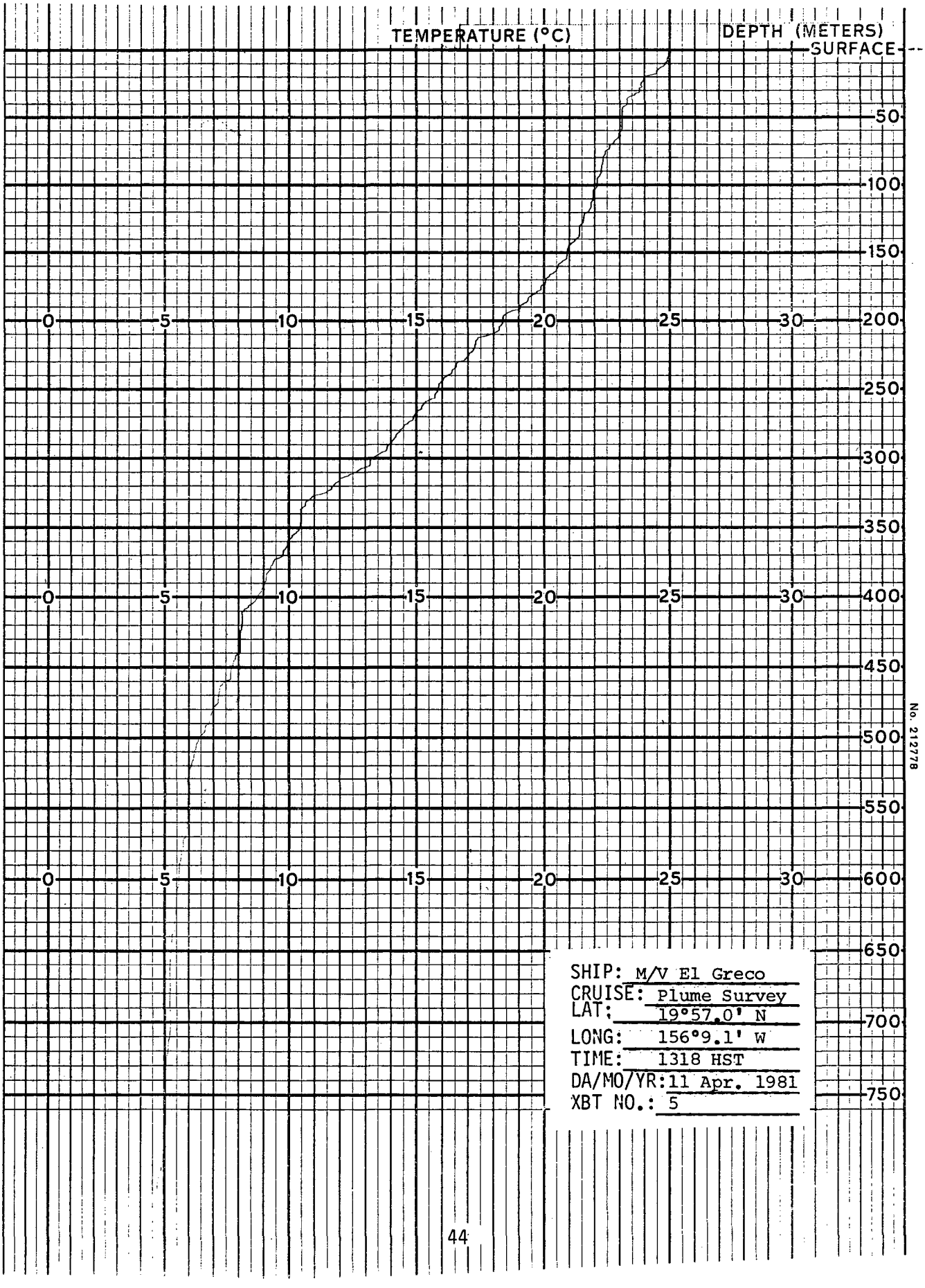
THE SIPPICAN CORP. MARION, MASS., U.S.A.

INCREASING DEPTH

THE SIPPICAN CORP. MARION, MASS.,

No. 212778


TEMPERATURE (°C)
DEPTH (METERS)
SURFACE
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
0
5
10
15
20
25
30
SHIP: M/V El Greco
CRUISE: Plume Survey
LAT: 19°57.2' N
LONG: 156°9.2' W
TIME: 1130 HST
DA/MO/YR: 11 Apr. 1981
XBT NO.: 4
THE SIPPICAN CORP. MARION, MASS., U.S.A.
INCREASING DEPTH
THE SIPPICAN CORP. MARION, MASS., U
No. 212778

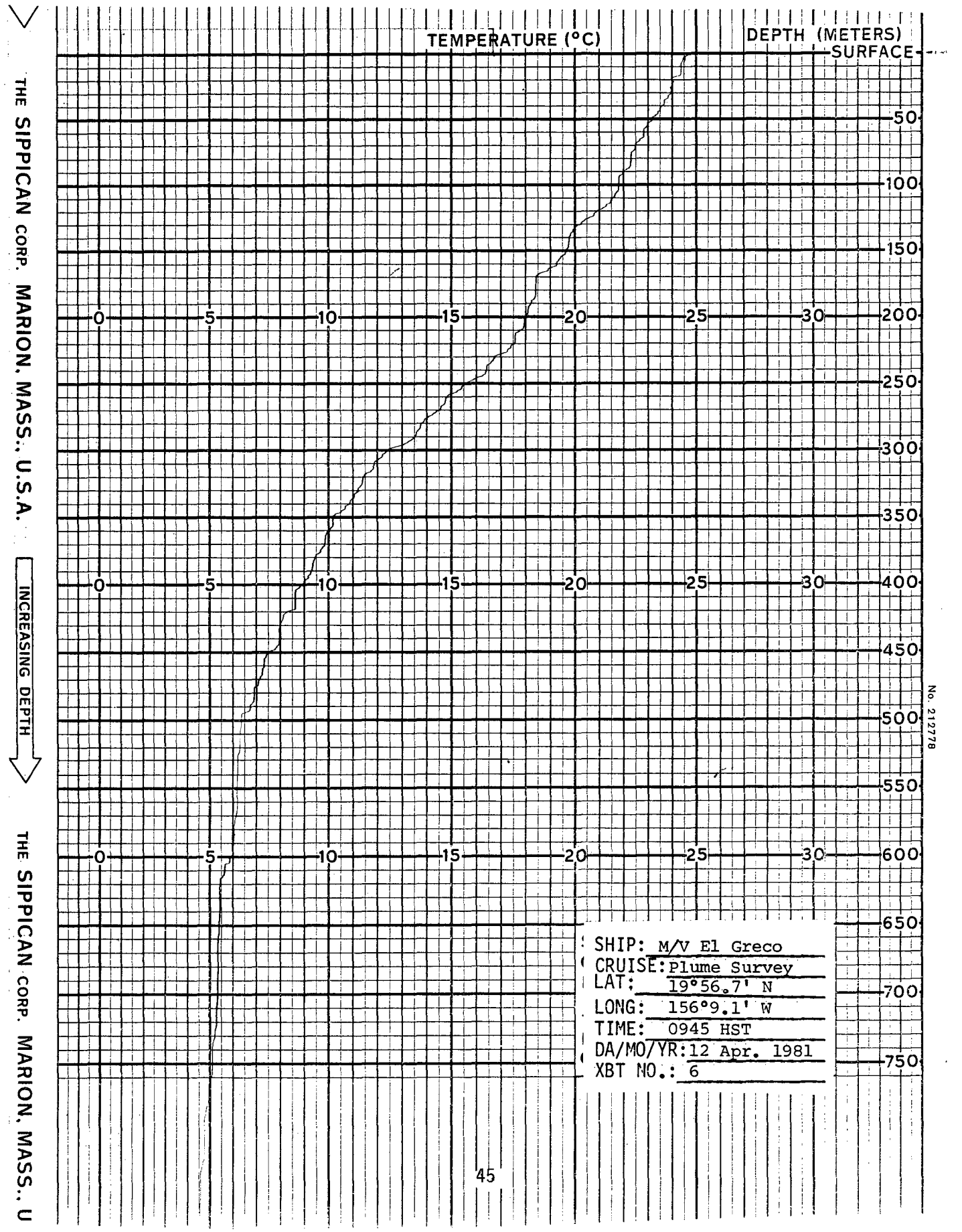


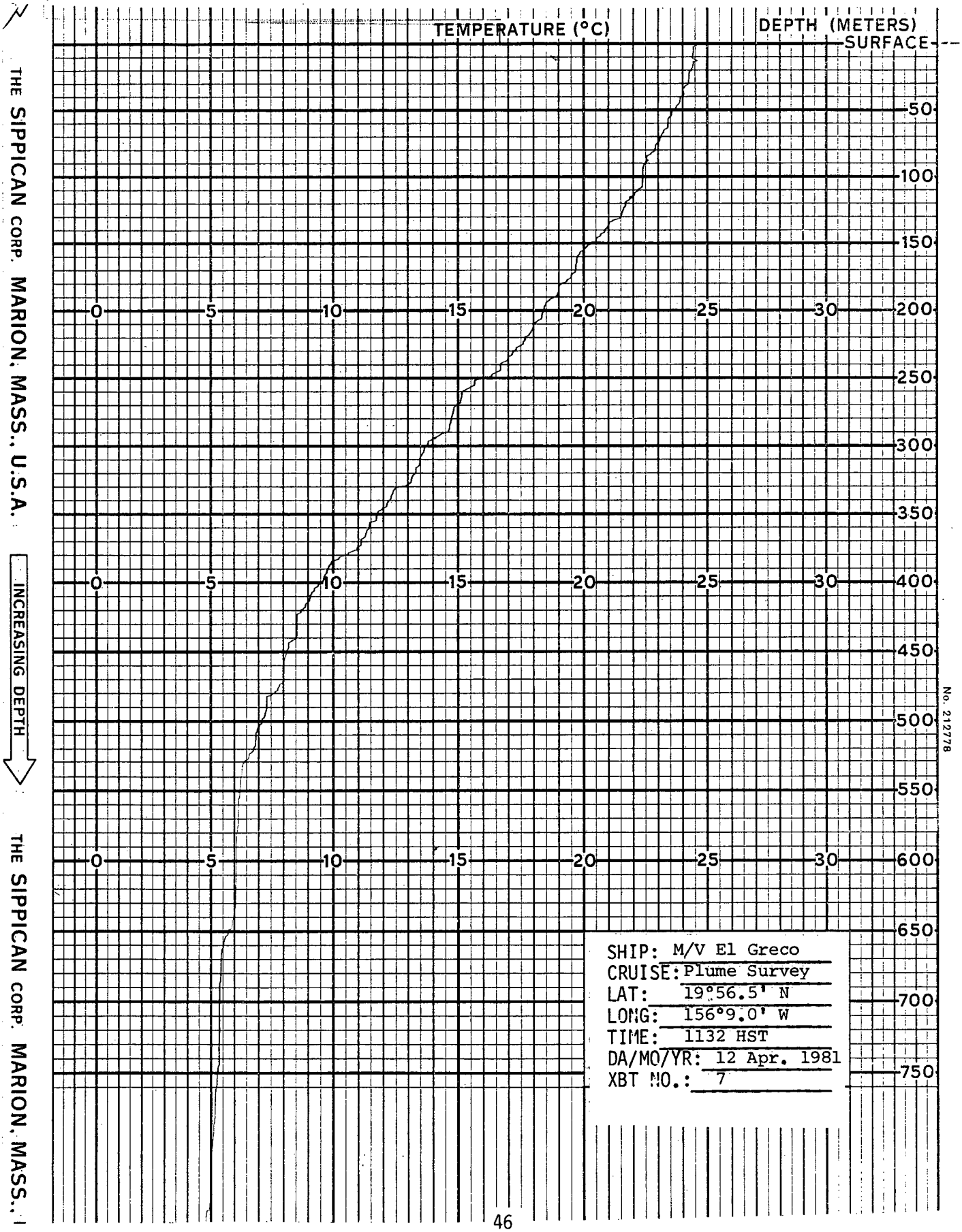
THE SIPPICAN CORP. MARION, MASS., U.S.A.

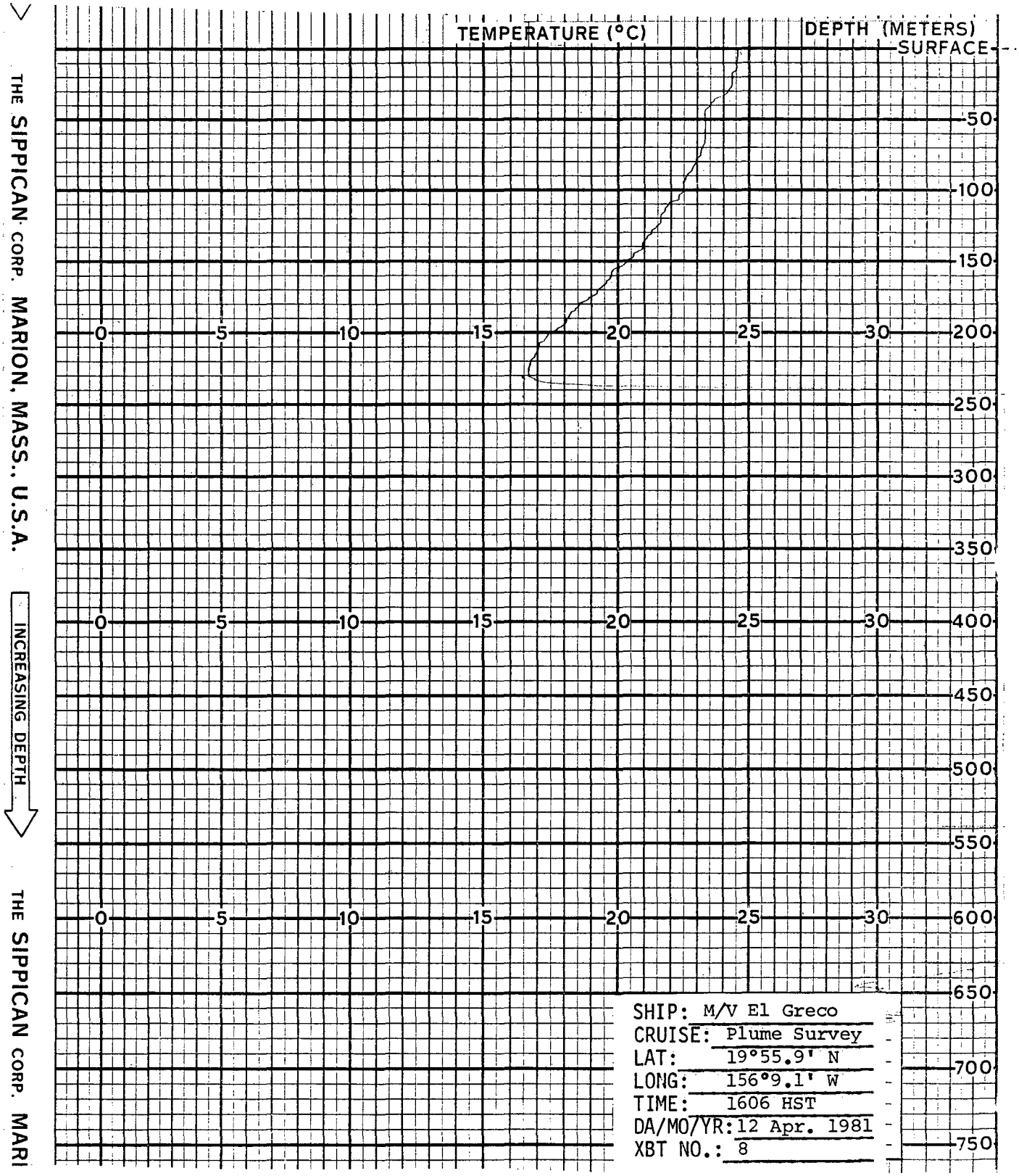
INCREASING DEPTH

THE SIPPICAN CORP. MARION, MASS., U.S.

No. 212778


TEMPERATURE (°C)
DEPTH (METERS)
SURFACE
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
0
5
10
15
20
25
30
SHIP: M/V El Greco
CRUISE: Plume Survey
LAT: 19°56.7' N
LONG: 156°9.1' W
TIME: 0945 HST
DA/MO/YR: 12 Apr. 1981
XBT NO.: 6
THE SIPPICAN CORP. MARION, MASS., U.S.A.
INCREASING DEPTH
THE SIPPICAN CORP. MARION, MASS., U
No. 212778


TEMPERATURE (°C)
DEPTH (METERS)
SURFACE
50
100
150
0
5
10
15
20
25
30
200
250
300
350
400
450
500
550
600
650
700
750
SHIP: M/V El Greco
CRUISE: Plume Survey
LAT: 19°56.5' N
LONG: 156°9.0' W
TIME: 1132 HST
DA/MO/YR: 12 Apr. 1981
XBT NO.: 7
THE SIPPICAN CORP. MARION, MASS., U.S.A.
INCREASING DEPTH
No. 212778


TEMPERATURE (°C)
DEPTH (METERS)
SURFACE
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
0
5
10
15
20
25
30
SHIP: M/V El Greco
CRUISE: Plume Survey
LAT: 19°55.9' N
LONG: 156°9.1' W
TIME: 1606 HST
DA/MO/YR: 12 Apr. 1981
XBT NO.: 8
THE SIPPICAN CORP. MARION, MASS., U.S.A.
INCREASING DEPTH
THE SIPPICAN CORP. MARI

OTEC-1 PLUME SURVEY

APPENDIX B

OCEAN ENERGY CONVERTER
OPERATIONS LOG

PLUME SURVEY

OTEC-1 MIXED-WATER DISCHARGE
OEC Operations Log: 11 April 1981

Time (HST)	OCEAN ENERGY CONVERTER POSITION x(m)	y(m)	Latitude	Longitude	OEC Heading (°T)	CURRENT Speed (cm/sec)	Direction (°M)	COMMENTS
0806	8,630	13,300	19°57.28'	156°10.06'	177	22.5	15.3	Current Meter at 30m
0815								Dye Sample No. 1, blank--before dye injection
0821								Start Dye Injection, pump speed 75 rpm
0900								Dye Sample No. 2, dye is visible in 1-liter sample but not visible in test tube dye sample
0929	9,063	13,287	19°57.27'	156°09.81'	189	23.5	32.3	
0935						20.8	34.7	
0941	9,131	13,302	19°57.28'	156°09.77'	191	20.3	32.8	
0951	9,208	13,276	19°57.27'	156°09.73'	193	18.5	41.2	
1000								Dye Sample No. 3
1014	9,346	13,251	19°57.25'	156°09.52'	205	18.8	36.7	
1037								Dye Flow Rate Increased, pump speed 150 rpm
1048	9,558	13,179	19°57.21'	156°09.52'	220	23.6	24.7	Dye Sample No. 4
1100								
1110	9,692	13,123	19°57.18'	156°09.45'	224			Current Profile Ongoing
1123								Pumping of Dye Stopped
1130								Dye Sample No. 5, sample appears clear
1135	9,818	13,073	19°57.16'	156°09.37'	231	29.8	09.8	Current Profile Complete, meter at 30m
1200								Dye Sample No. 6, sample appears clear
1230								Start Dye Injection, pump speed 300 rpm
1247	10,075	12,890	19°57.06'	156°09.23'	237	36.7	30.8	
1300								Dye Sample No. 7; patches of dye visible off stern of OEC
1301	10,090	12,864	19°57.04'	156°09.22'	240	34.0	35.2	
1319	10,114	12,827	19°57.02'	156°09.20'	242	28.5	31.6	
1325								Start Current Profile 25-150m in 25m intervals
1348								Current Meter Secured at 30m
1400								Dye Sample No. 8; dye visible in sample

PLUME SURVEY

OTEC-1 MIXED-WATER DISCHARGE

OEC Operations Log: 11 April 1981

Time (HST)	OCEAN ENERGY CONVERTER POSITION x(m)	y(m)	Latitude	Longitude	OEC Heading (°T)	CURRENT Speed (cm/sec)	Direction (°M)	COMMENTS
1402	10,150	12,723	19°56.96'	156°09.18'	245	27.4	41.7	
1411	10,160	12,697	19°56.95'	156°09.18'	247	26.7	44.7	
1425	10,174	12,654	19°56.93'	156°09.17'	249	32.9	25.8	
1448	10,199	12,585	19°56.89'	156°09.16'	254	28.7	37.8	
1500								Dye Sample No. 9
1504	10,222	12,534	19°56.86'	156°09.14'	258	27.1	39.2	
1520								Start Current Profile, 25-150m in 25m intervals
1548								End Current Profile; see Appendix D for data current meter secured at 30m
1523	10,260	12,453	19°56.82'	156°09.12'	260	23.0	353.6	
1600								Dye Sample No. 10
1601	10,347	12,291	19°56.73'	156°09.07'	262	32.3	44.6	
1613	10,355	12,237	19°56.70'	156°09.07'	262	25.8	52.0	
1620								Start Current Profile, 25-150m in 25m intervals
1624	10,391	12,225	19°56.69'	156°09.05'	264	41.2	0.5	
1638	10,412	12,203	19°56.68'	156°09.03'	264	27.6	50.6	
1642								End Current Profile; see Appendix D for data current meter secured at 25m
1700								Dye Sample No. 11
1718	10,421	12,267	19°56.72'	156°09.03'	264	24.0	90.8	
1719								Dye Injection Stopped
1730	10,423	12,298	19°56.73'	156°09.03'	262	17.6	57.1	
1800								Dye Sample No. 12
1801	10,401	12,355	19°56.76'	156°09.04'	256	16.0	80.9	
1836	10,384	12,462	19°56.82'	156°09.05'	257	12.2	77.2	
1925	10,343	12,536	19°56.86'	156°09.07'	252	10.6	101.0	
2004	10,267	12,683	19°56.94'	156°09.12'	246	8.7	47.6	
2102	10,177	12,838	19°57.03'	156°09.17'	242	12.2	38.0	
2130								Start Dye Injection, pump speed 75 rpm
2200	10,190	12,903	19°57.06'	156°09.16'	237	22.4	37.6	

PLUME SURVEY

OTEC-1 MIXED-WATER DISCHARGE
OEC Operations Log: 12 April 1981

Time (HST)	OCEAN ENERGY CONVERTER POSITION x(m)	y(m)	Latitude	Longitude	OEC Heading (°T)	CURRENT Speed (cm/sec)	Direction (°M)	COMMENTS
0040								Dye Injection Stopped
0701	9,935	12,706	19°56.95'	156°09.31'	240	24.6	22.9	
0723	9,971	12,663	19°56.93'	156°09.29'	237	25.0	35.3	
0833	10,165	12,467	19°56.82'	156°09.18'	252	32.0	53.9	
0850	10,194	12,420	19°56.80'	156°09.16'	252	39.0	49.1	
0907	10,222	12,375	19°56.77'	156°09.14'	260	23.8	43.1	
0914	10,246	12,342	19°56.76'	156°09.13'	262	27.9	47.9	Dye Injection Started; pump speed 75 rpm
0930								Increase Dye Flow Rate to 300 rpm
0946	10,325	12,280	19°56.72'	156°09.08'	266	38.4	62.4	
0955								Dye Flow Rate Reduced to 150 rpm
1005								Dye Flow Rate Reduced to 75 rpm
1019	10,419	12,180	19°56.67'	156°09.03'	264	47.5	63.1	
1024								Dye Injection Stopped
1054								Dye Injection Started, pump speed 75 rpm
1055								Dye Injection Stopped
1104								Dye Injection Started, pump speed 75 rpm
1108								Dye Injection Stopped
1114								Dye Injection Started, pump speed 75 rpm
1125					268	40.5	67.6	
1145								Dye Injection Stopped
1200								Dye Injection Started, pump speed 75 rpm
1224	10,543	11,660	19°56.38'	156°08.96'	276	40.9	86.4	
1235	10,539	11,608	19°56.36'	156°08.96'	277	41.3	84.3	
1236								Dye Injection Stopped
1244								Start Current Profile
1355	10,470	11,161	19°56.11'	156°09.00'	288	34.1	92.0	End Current Profile; see Appendix D for data
1433	10,384	10,863	19°55.95'	156°09.05'	294	37.4	88.9	
1455	10,300	10,704	19°55.86'	156°09.10'	301	36.0	88.0	

OTEC-1 PLUME SURVEY

APPENDIX C

DISCHARGE FLOW AND ENVIRONMENTAL DATA

OTEC-1 PLUME SURVEY

DISCHARGE FLOW AND ENVIRONMENTAL DATA
11 April 1981

Time Interval (HST)	Warm Water[1] Flow (gpm)	Cold Water[1] Flow (gpm)	Mixed-Water[1] Flow (gpm)	Mixed-Water[1] Temp. (°F)	Wind Speed (knots)	Wind Direction (from °M)	OEC[2] Heading (°T)	Wave[2] Height (m)	Air[2] Temp. (°F)	Wet Bulb[2] Temp. (°F)	Barometric[2] Pressure (mb)	Current[2,3] Speed (cm/sec)	Current[2,3] Direction[4] (°M)
0700-0800	86,310	68,940	155,250	63.69	7.9	273							
0800-0900	86,300	66,750	153,050	63.76	6.4	84	183	1.3	76	69	1015.2	25.3	020
0900-1000	85,960	66,390	152,350	63,82	5.6	47							
1000-1100	87,200	68,280	155,480	63.92	3.8	286	205	1.1	82	72	1015.7	29.1	028
1100-1200	87,000	67,600	154,600	64.06	4.4	63							
1200-1300	87,000	70,200	157,200	64.05	1.0	44	240	0.8	85	74	1014.8	33.9	035
1300-1400	86,800	68,330	155,130	64.28	2.6	29							
1400-1500	87,570	67,850	155,420	64.48	4.0	25	264	0.9	81	70	1012.2	28.6	054
1500-1600	87,370	68,320	155,690	64.38	4.4	346							
1600-1700	87,350	68,930	156,280	64.02	8.9	48	264	1.0	80	70	1012.0	28.0	054
1700-1800	87,010	69,790	156,800	64.22	11.2	43							
1800-1900	87,810	69,380	157,190	64.06	10.7	45	263	1.2	76	68	1012.5	13.0	056
1900-2000	88,020	65,220	153,240	63.98	8.0	42							
2000-2100	88,330	61,580	149,910	63.87	8.2	37	252	0.8	73	68	1013.2	10.0	048
2100-2200	87,900	67,810	155,710	63.84	6.2	36							
2200-2300	87,690	69,590	157,280	63.78	6.8	21	238	0.8	73	68	1014.8	26.0	030
2300-2400	86,700	68,850	155,550	63.65	11.6	30							

[1] One hour average data

[2] Instantaneous reading on the even hour

[3] 0700 to 1700, 11 April 1981, current meter located at 30m water depth
1800, 11 April 1981, to 1200, 12 April 1981, current meter located at 25m water depth

[4] Current direction toward which current is flowing

OTEC-1 PLUME SURVEY

DISCHARGE FLOW AND ENVIRONMENTAL DATA
12 April 1981

Time Interval (HST)	Warm Water[1] Flow (gpm)	Cold Water[1] Flow (gpm)	Mixed-Water[1] Flow (gpm)	Mixed-Water[1] Temp. (°F)	Wind Speed (knots)	Wind Direction (from °M)	OEC[2] Heading (°T)	Wave[2] Height (m)	Air[2] Temp. (°F)	Wet Bulb[2] Temp. (°F)	Barometric[2] Pressure (mb)	Current[2,3] Speed (cm/sec)	Current[2,3] Direction[4] (°M)
0000-0100	87,080	69,730	156,810	63.42	9.1	33	225	0.7	72	67	1014.8	33.4	055
0100-0200	86,870	69,870	156,740	63.37	6.0	16							
0200-0300	87,120	68,820	155,940	63.40	5.5	20	235	0.8	72	67	1014.0	20.3	035
0300-0400	86,860	67,800	154,660	63.36	7.2	27							
0400-0500	87,450	68,010	155,460	63.39	4.9	355	240	0.9	72	67	1013.8	10.1	021
0500-0600	87,500	68,870	156,370	63.35	5.1	329							
0600-0700	87,710	69,050	156,760	63.38	4.6	343	245	0.7	72	66	1014.0	13.4	020
0700-0800	86,930	67,410	154,340	63.37	4.0	329							
0800-0900	87,920	70,220	158,140	63.49	4.4	72	240	0.6	78	71	1014.2	26.3	050
0900-1000	87,660	71,270	158,930	63.62	5.3	14							
1000-1100	87,500	68,510	156,010	63.66	5.7	348	265	0.7	78	70	1014.0	46.5	060
1100-1200	86,480	70,770	157,250	63.90	4.1	335							
1200-1300	87,080	70,290	157,370	63.98	7.4	328	272	1.0	80	70	1014.0	37.9	082
1300-1400	87,300	70,500	157,800	64.02	11.9	320							
1400-1500	87,290	70,780	158,070	64.06	13.1	301							
1500-1600	75,750	65,400	141,150	62.27	15.4	285							
1600-1700	26,790	21,290	48,080	67.59	17.2	85							
1700-1800	26,220	20,230	46,450	71.94	18.8	75							
1800-1900	17,300	19,350	36,650	75.11	20.9	55							
1900-2000	11,630	23,030	34,660	74.44	21.6	50							

[1]One hour average data
[2]Instantaneous reading on the even hour
[3]0700 to 1700, 11 April 1981 current meter located at 30m water depth
1800, 11 April 1981 to 1200, 12 April 1981 current meter located at 25m water depth
[4]Current direction toward which current is flowing

OTEC-1 PLUME SURVEY

APPENDIX D

CURRENT PROFILE DATA

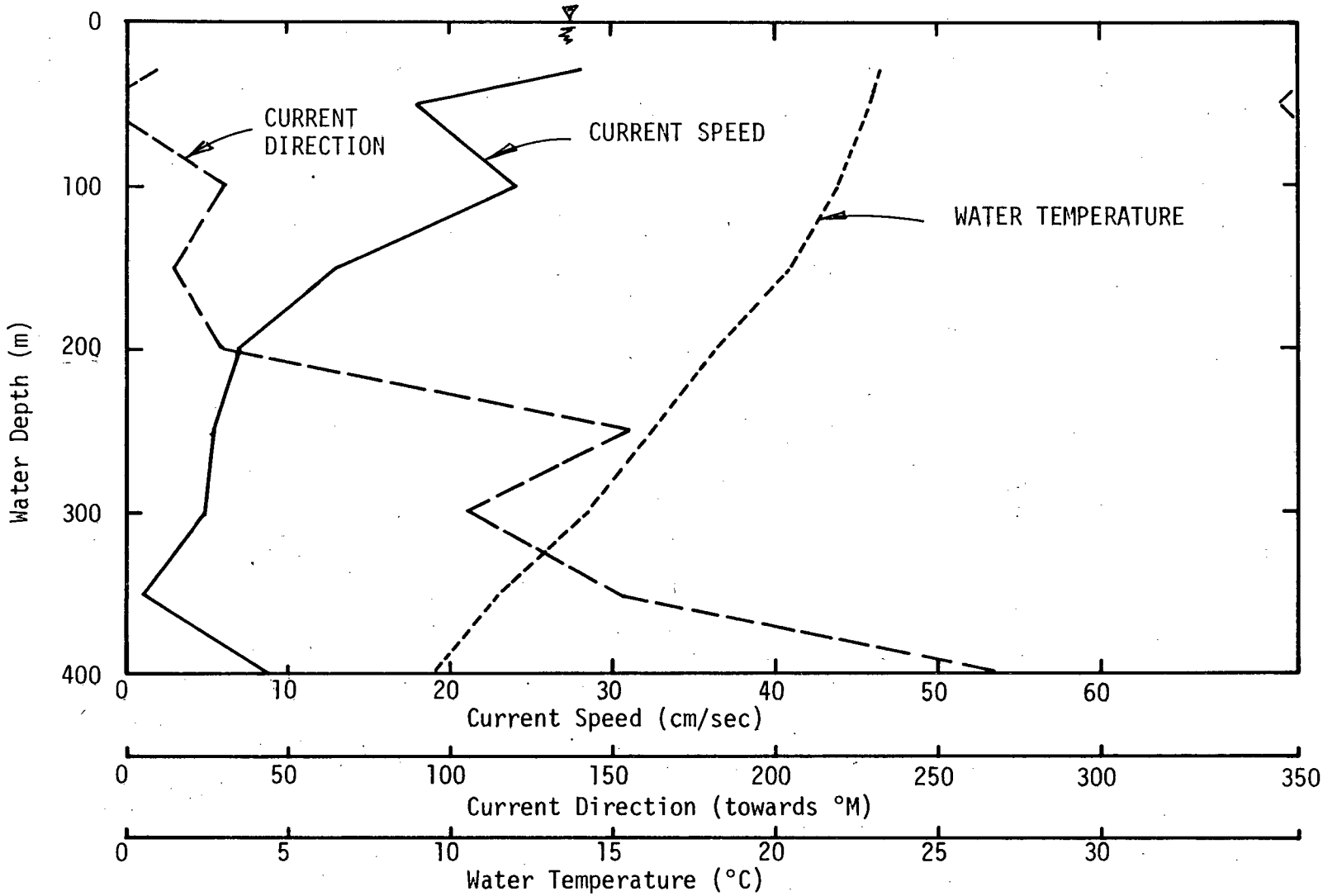


FIGURE D1. CURRENT AND TEMPERATURE PROFILE DATA FROM THE OCEAN ENERGY CONVERTER 1105-1135 HST, APRIL 11, 1981

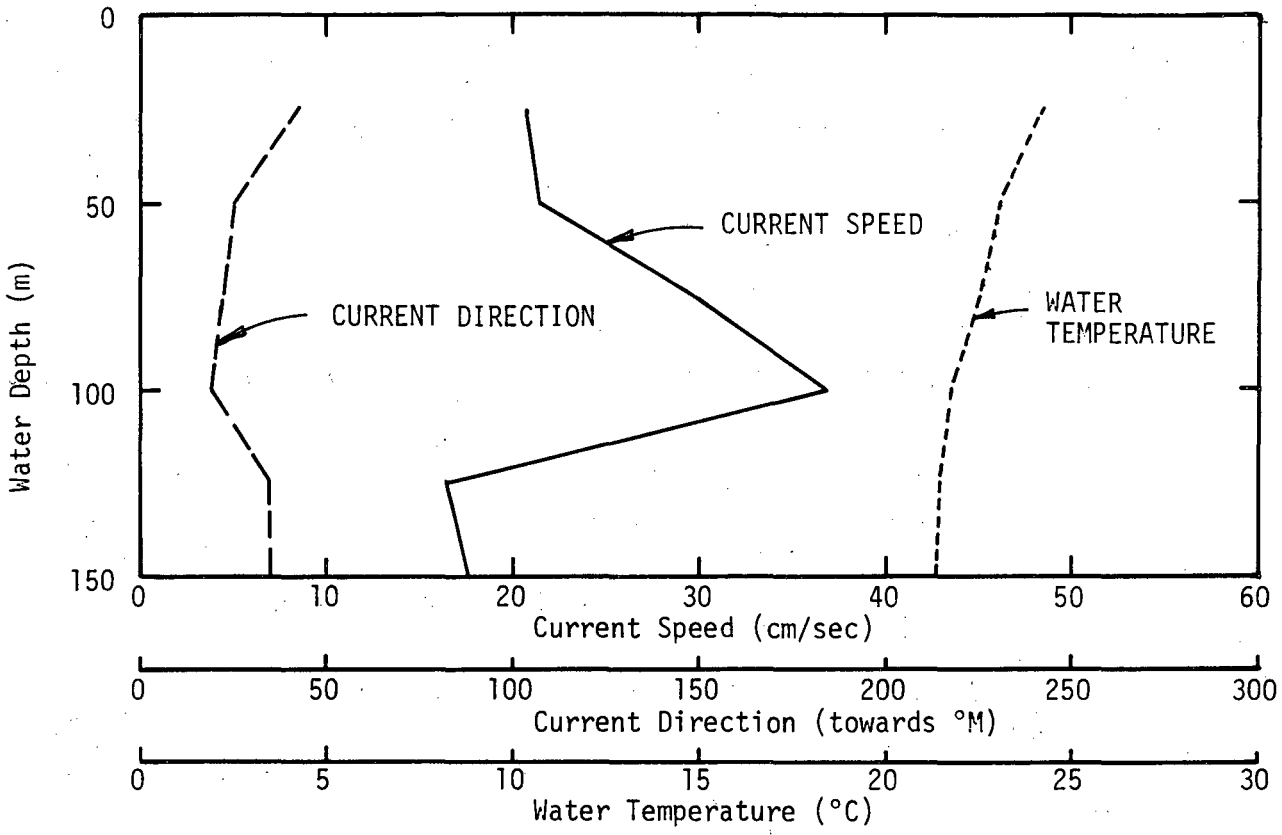


FIGURE D2. CURRENT AND TEMPERATURE PROFILE DATA FROM THE OCEAN ENERGY CONVERTER 1325-1348, APRIL 11, 1981

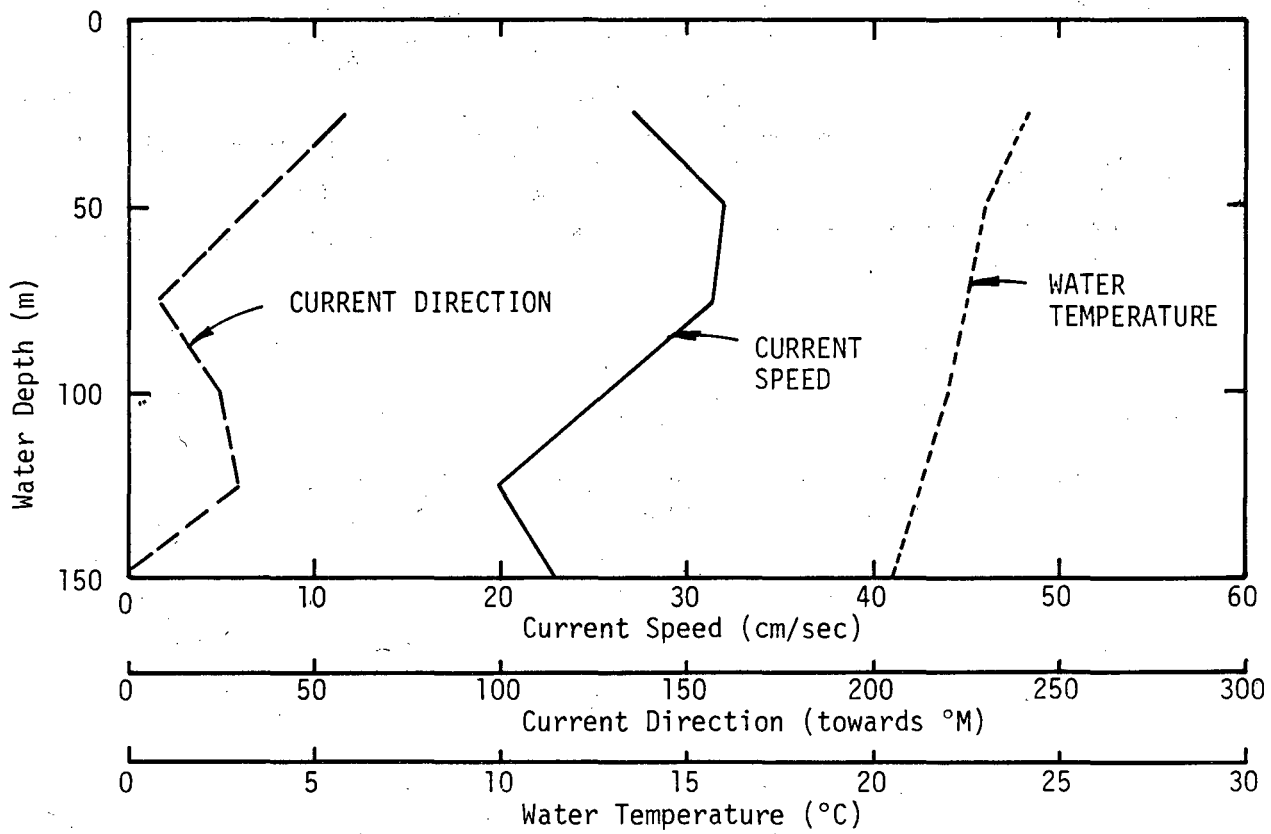


FIGURE D3. CURRENT AND TEMPERATURE PROFILE DATA FROM THE OCEAN ENERGY CONVERTER 1520-1548 HST, APRIL 11, 1981

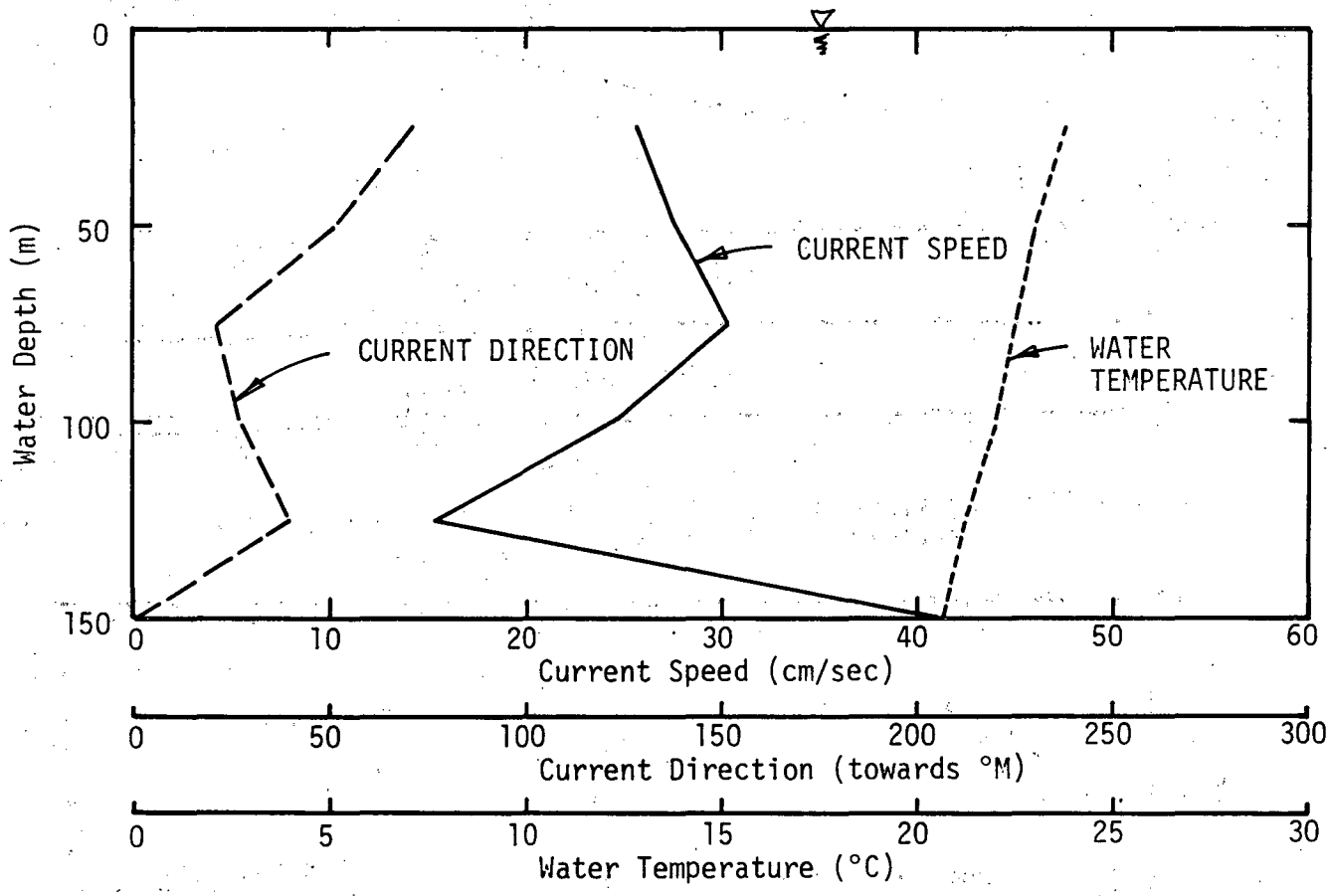


FIGURE D4. CURRENT AND TEMPERATURE PROFILE DATA FROM THE OCEAN ENERGY CONVERTER 1620-1642HST, APRIL 11, 1981

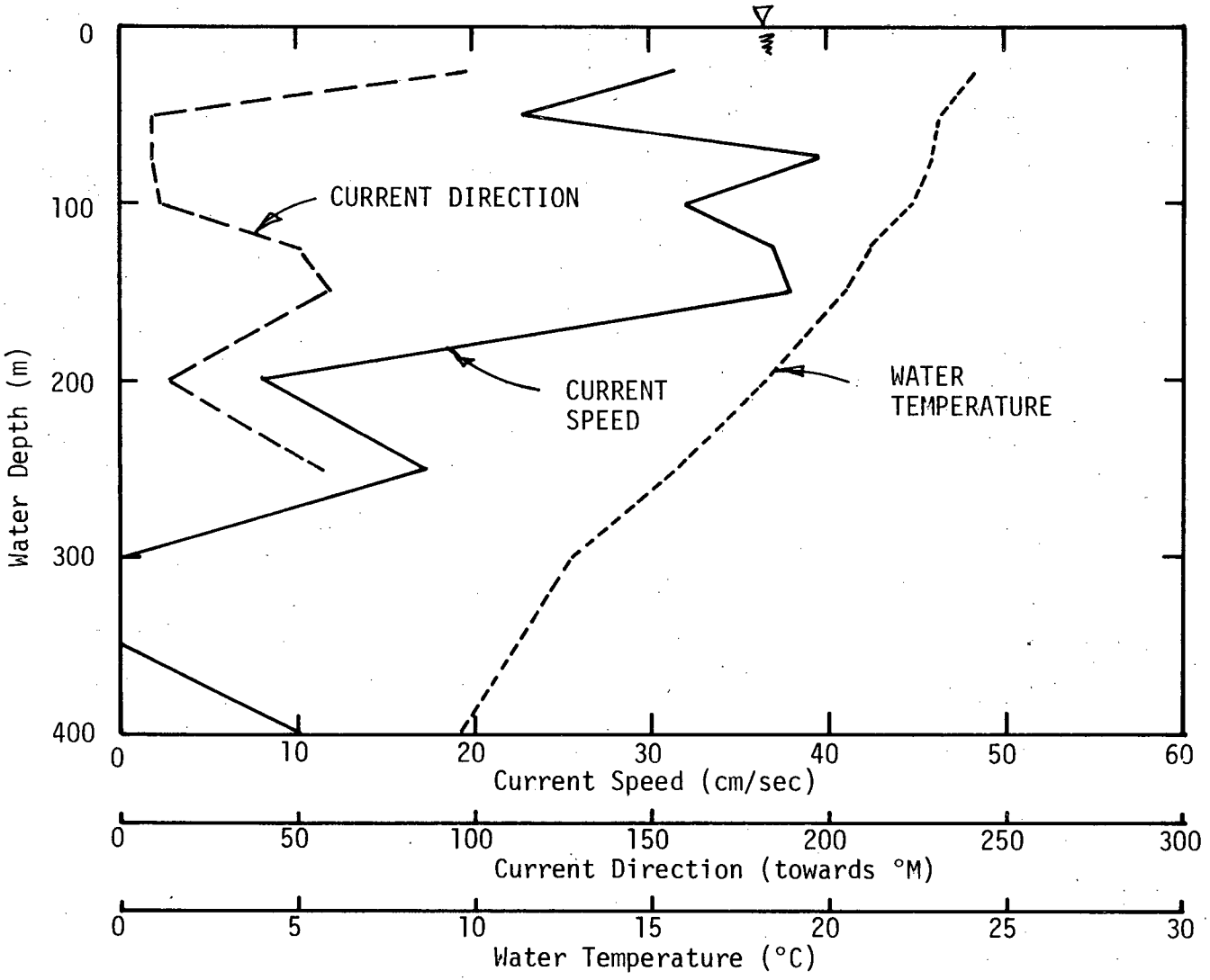


FIGURE D5. CURRENT AND TEMPERATURE PROFILE DATA FROM THE OCEAN ENERGY CONVERTER 1244-1355 HST, APRIL 12, 1981

PLUME SURVEY

OTEC-1 MIXED-WATER DISCHARGE
CURRENT PROFILE DATA

Date: 11 April 1981 Time (HST): 1105-1135
Location: Ocean Energy Converter

Water Depth (m)	Current Speed (cm/sec)	Current Direction (towards °M)	Water Temperature (°C)
30	28.2	010	23.3
50	18.0	355	23.0
100	24.2	032	22.0
150	13.0	016	20.5
200	7.0	030	18.2
250	5.5	155	16.2
300	5.0	105	14.2
350	1.1	151	11.6
400	8.7	270	9.5

PLUME SURVEY

OTEC-1 MIXED-WATER DISCHARGE
CURRENT PROFILE DATA

Date: 11 April 1981 Time (HST): 1325-1348
Location: Ocean Energy Converter

Water Depth (m)	Current Speed (cm/sec)	Current Direction (towards °M)	Water Temperature (°C)
25	20.7	043	24.3
50	21.3	027	23.1
75	29.6	023	22.6
100	36.8	019	21.8
125	16.5	035	21.4
150	17.6	036	21.3

PLUME SURVEY

OTEC-1 MIXED-WATER DISCHARGE
CURRENT PROFILE DATA

Date: 11 April 1981 Time (HST): 1520-1548
Location: Ocean Energy Converter

Water Depth (m)	Current Speed (cm/sec)	Current Direction (towards °M)	Water Temperature (°C)
25	27.2	058	24.2
50	31.9	033	23.0
75	31.5	008	22.6
100	25.9	025	22.0
125	19.8	029	21.3
150	23.0	354	20.6

PLUME SURVEY

OTEC-1 MIXED-WATER DISCHARGE
CURRENT PROFILE DATA

Date: 11 April 1981 Time (HST): 1620-1642
Location: Ocean Energy Converter

Water Depth (m)	Current Speed (cm/sec)	Current Direction (towards °M)	Water Temperature (°C)
25	25.6	071	23.8
50	27.6	051	23.0
75	30.2	021	22.5
100	24.5	027	22.0
125	15.2	039	21.2
150	41.2	001	20.7

PLUME SURVEY

OTEC-1 MIXED-WATER DISCHARGE
CURRENT PROFILE DATA

Date: 12 April 1981 Time (HST): 1244-1355
Location: Ocean Energy Converter

Water Depth (m)	Current Speed (cm/sec)	Current Direction (towards °M)	Water Temperature (°C)
25	31.3	093	24.2
50	22.8	019	23.2
75	39.6	018	22.9
100	31.9	022	22.4
125	36.8	051	21.4
150	37.9	068	20.4
200	7.9	027	18.2
250	17.1	063	15.7
300	0.0	-	12.7
350	0.0	-	11.2
400	10.0	008	9.6

OTEC-1 PLUME SURVEY

APPENDIX E

VERTICAL PROFILE FLUOROMETER DATA

PLUME SURVEY

OTEC-1 MIXED-WATER DISCHARGE
11 April 1981

Vertical Profile No. 4

Profile Time(HST): 1249-1259

Profile Location: Approximately 23 meters downstream of the discharge location (see Figure in comments)

Discharge Flow Conditions

Mixed-Water Discharge Flow Rate (gpm):	157,200
Injected Dye Flow Rate (gpm):	0.0666
Calculated Dye Concentration in Mixed-Water Discharge[2] (ppm):	0.424

Data from Ocean Energy Converter at 1247 HST

Heading (°T) 237, Current Speed (cm/sec) 36.7, Current Direction (°M) 30.8

x,y Location of Discharge[4]: x = 10,126

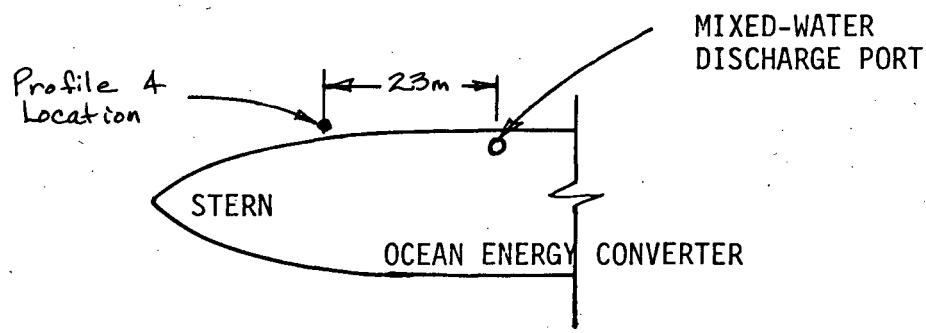
y = 12,923

Plume Profile Data

Plume Vertical Location: Between 20-25m from surface

Maximum Fluorometer Reading:	61
Maximum Dye Concentration (ppm):	0.035
Calculated Dilution of Maximum Concentration:	12.2
Estimated Plume Thickness (m):	<5m

Comments:



PLUME SURVEY

OTEC-1 MIXED-WATER DISCHARGE
11 April 1981

Vertical Profile No. 5

Profile Time(HST): 1301-1320

Profile Location: Approximatel6 45 meters downstream of the discharge location (see Figure in comments)

Discharge Flow Conditions

Mixed-Water Discharge Flow Rate (gpm):	155,130
Injected Dye Flow Rate (gpm):	0.0666
Calculated Dye Concentration in Mixed-Water Discharge[2] (ppm):	0.429

Data from Ocean Energy Converter at 1301 HST

Heading (°T) 240, Current Speed (cm/sec) 34.0, Current Direction (°M) 35.2

x,y Location of Discharge[4]: x = 10,114

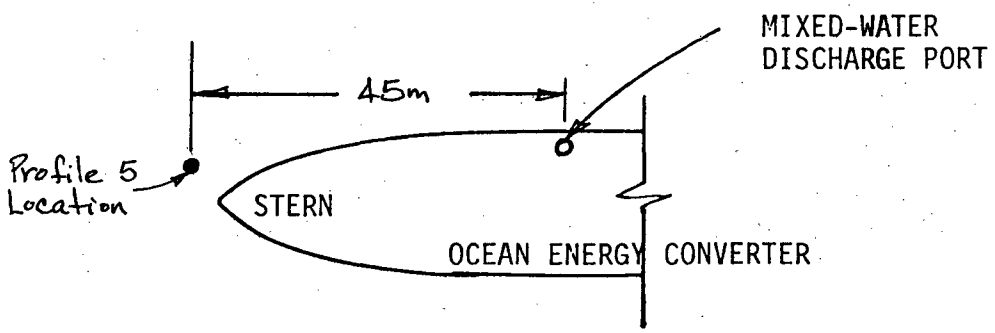
y = 12,895

Plume Profile Data

Plume Vertical Location: Between 30-35m from surface

Maximum Fluorometer Reading:	75
Maximum Dye Concentration (ppm):	0.043
Calculated Dilution of Maximum Concentration:	10.0
Estimated Plume Thickness (m):	<5

Comments:



PLUME SURVEY

OTEC-1 MIXED-WATER DISCHARGE
11 April 1981

Vertical Profile No. 6

Profile Time(HST): 1320-1345

Profile Location: Approximately 36 meters downstream of the discharge location (see Figure in comments).

Discharge Flow Conditions

Mixed-Water Discharge Flow Rate (gpm):	155,130
Injected Dye Flow Rate (gpm):	0.0666
Calculated Dye Concentration in Mixed-Water Discharge[2] (ppm):	0.429

Data from Ocean Energy Converter at 1319 HST

Heading (°T) ~242, Current Speed (cm/sec) 28.5, Current Direction (°M) 31.6

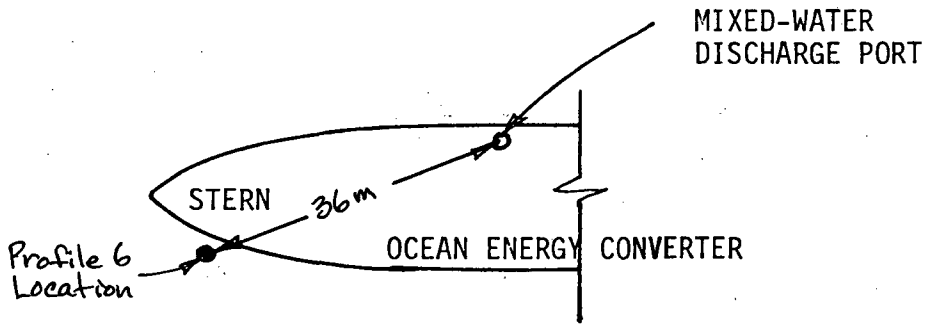
x,y Location of Discharge[4]: x = 10,168

y = 12,856

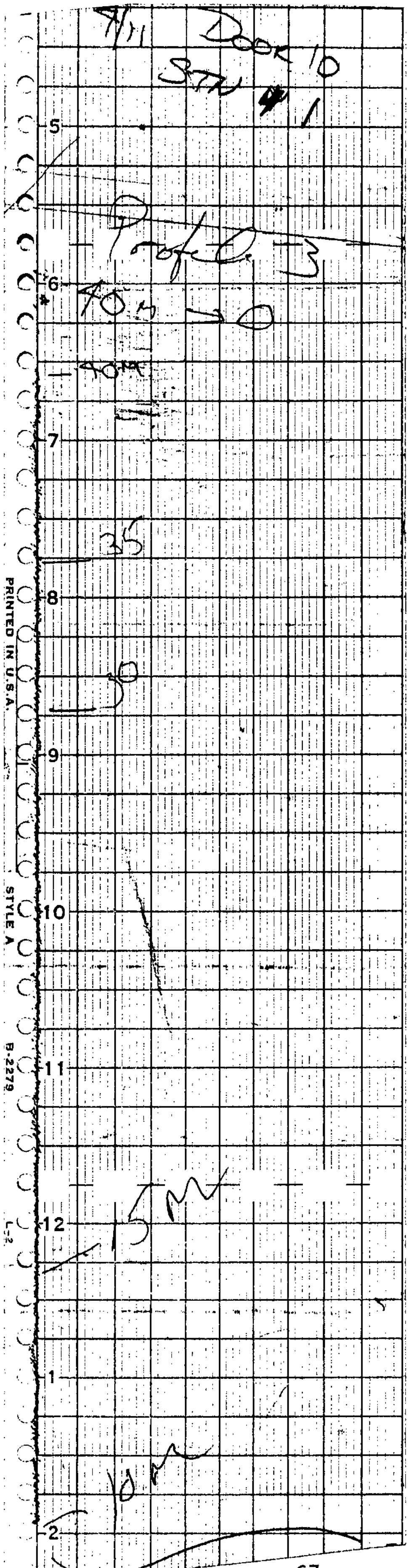
Plume Profile Data

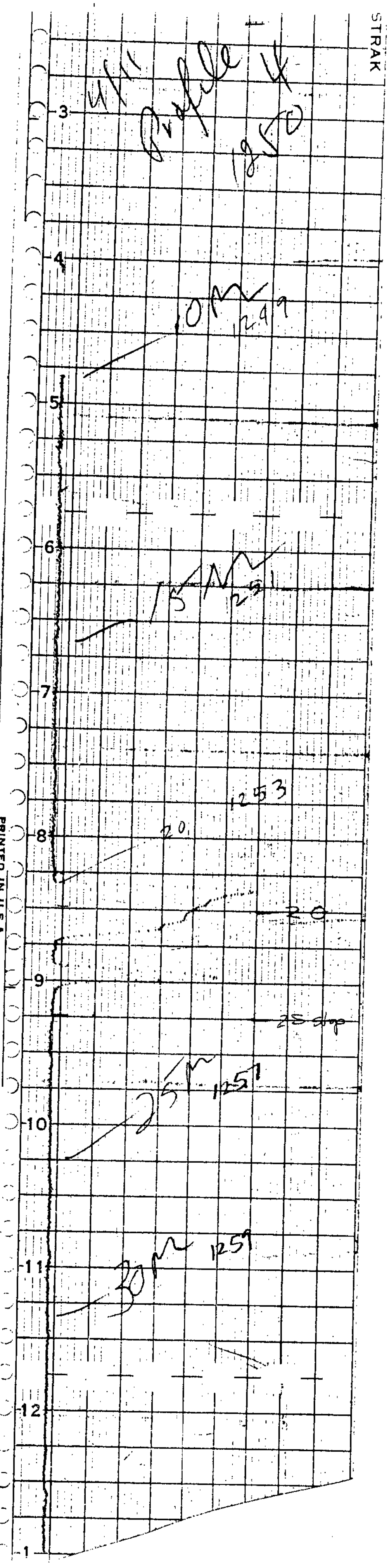
Plume Vertical Location:	Between 25-30m from surface
Maximum Fluorometer Reading:	74
Maximum Dye Concentration (ppm):	0.042
Calculated Dilution of Maximum Concentration:	10.2
Estimated Plume Thickness (m):	~5

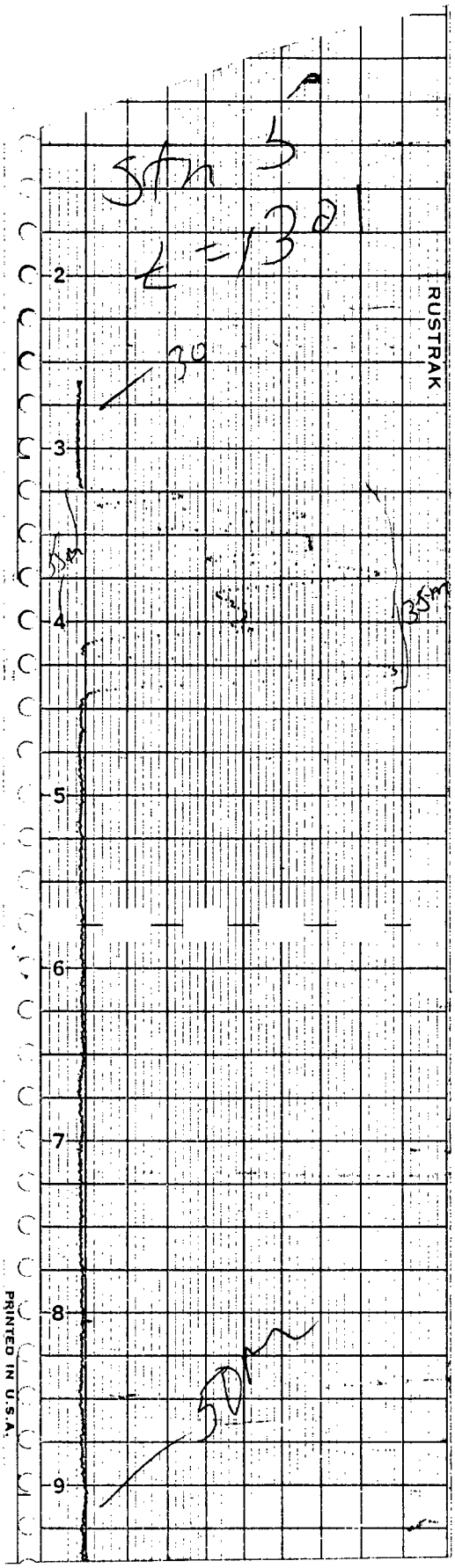
Comments:

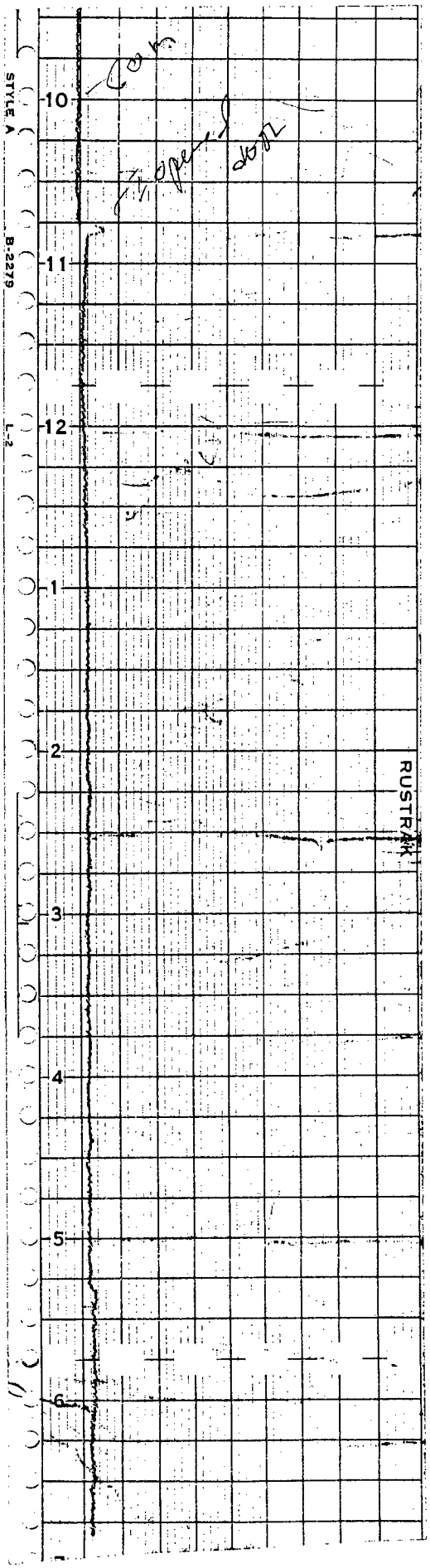


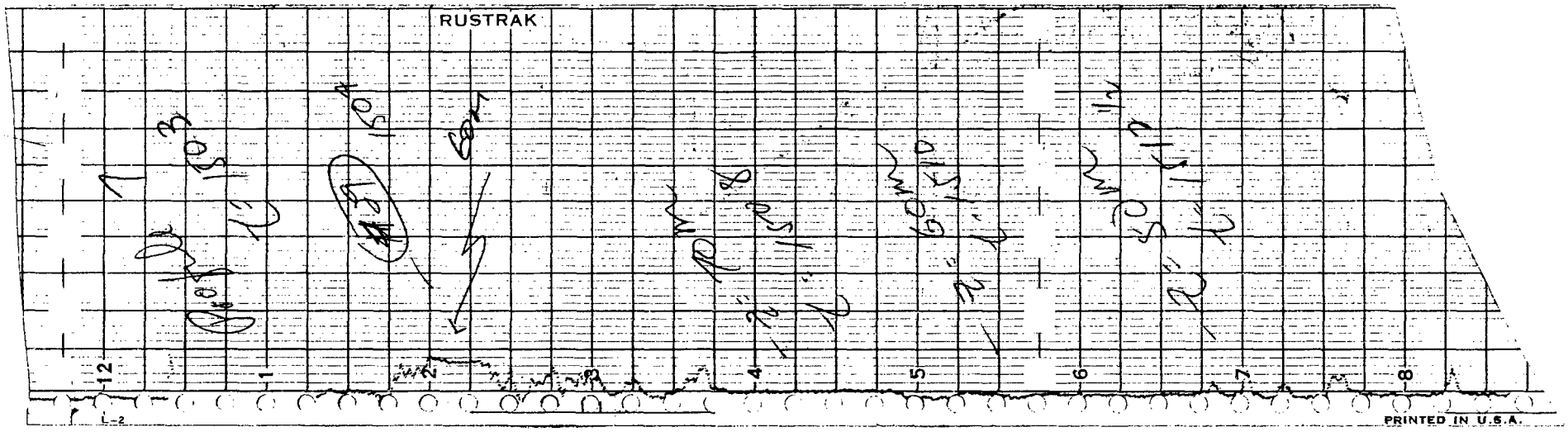
Reviewing the fluorometer strip chart record, while the record may seem to indicate that the plume extends from 30-20 meters, it should be noted that there is a residence time of the fluid in the hose system of about 1 minute. Thus from the 25 meter location as the pump is raised to the 20 meter depth, it takes about one minute for the water to reflect any change in height.

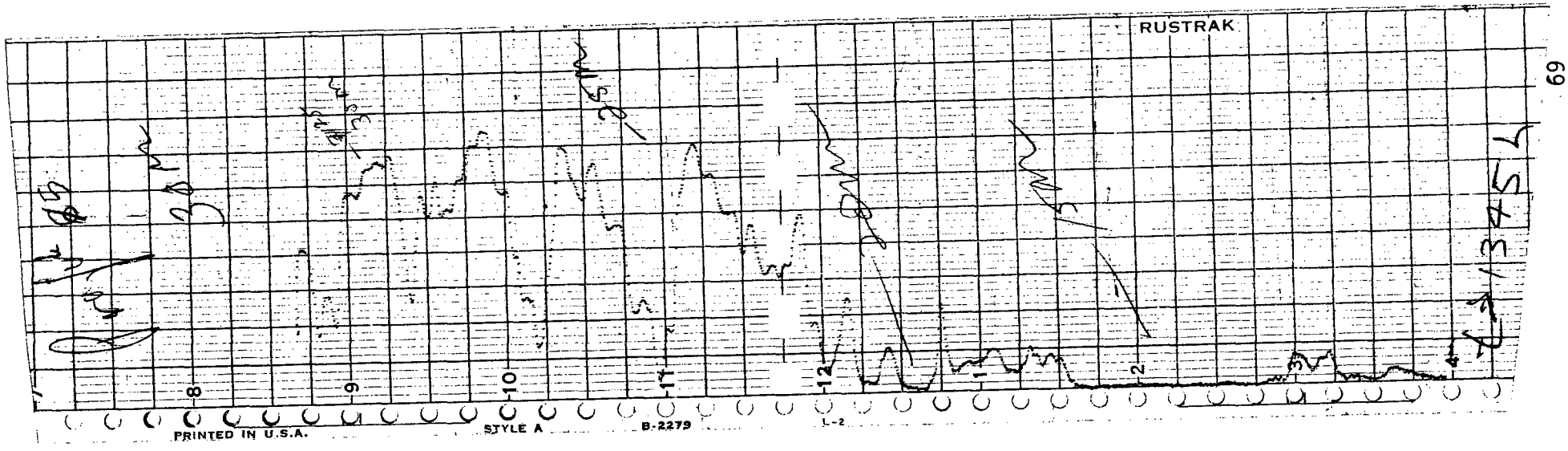

Dock 10
STN #1
Profile 3
40m 30
40m
35
30
15M
10m
PRINTED IN U.S.A.
STYLE A
B-2279
L-2


STRAK
Profile 4
1850
10M 1249
15M 1251
1253
20
20
25 stop
25M 1257
30M 1259
PRINTED IN U.S.A.
STYLE A
B-2279
L-2


RUSTRAK
PRINTED IN U.S.A.


STYLE A
B-2279
L-2
RUSTRAK


RUSTRAK
12
1
2
3
4
5
6
7
8
L-2
PRINTED IN U.S.A.


RUSTRAK
8
9
10
11
12
1
2
3
4
PRINTED IN U.S.A.
STYLE A
B-2279
L-2

OTEC-1 PLUME SURVEY

APPENDIX F

PLUME MAPPING HORIZONTAL TOW FLUOROMETER DATA

PLUME SURVEY

OTEC-1 MIXED-WATER DISCHARGE
11 April 1981

Tow No. 1

Tow Time (HST): 1355-1404 Wire Out (m)[1]: 40

Wire Angle (from Vertical): 27° Depth of Submerged Pump Intake (m): 36

Discharged Flow Conditions

Mixed-Water Discharge Flow Rate (gpm):	155,130
Injected Dye Flow Rate (gpm):	0.0666
Calculated Dye Concentration in Mixed-Water Discharge[2] (ppm):	0.43
Mixed-Water Discharge Temperature (°F):	64.3

Data from Ocean Energy Converter at 1402 HST

Heading (°T): 245, Current Speed (cm/sec): 27.4, Current Direction (°M): 41.7

Plume Data:

Maximum Fluorometer Reading:	15
Maximum Calculated Dye Concentration (ppm):	0.009
Calculated Dilution of Maximum Concentration:	50
Elapse Time of Plume Dye Readings (sec):	18
Approximate Travel Distance Across Dyed Plume (m):	11
Distance from Discharge Point to Plume (m)	115

Original Mixed-Water Discharge Location of Dye Reading[3,4]: x_0(m) = 10,192
y_0(m) = 12,782

SURVEY VESSEL LOCATION DATA

Time (HST)	Survey Vessel Position[4,5] x(m)	y(m)	Position of Survey Vessel Relative To Discharge Location x_0,y_0 x(m)	y(m)
1358	10,322	12,813	130	31
1359	10,296	12,852	104	70
1400	10,255	12,856	63	74
1401	10,222	12,889	30	107
1402	10,199	12,878	7	96
1403	10,179	12,874	-13	92

[1]0 Reading at the Water Surface
[2]Dye Flow Rate/Mixed-Water Discharge Flow Rate
[3]The Original Mixed-Water Discharge Location is Obtained by Back Integrating from the Dye Reading Position using Current Speed and Direction to Obtain the Position of the Discharge Location from which the Measured Dye Water was Discharged
[4]An Arbitrary x,y Coordinate System has been Established Centered at Latitude 19°50'N, Longitude 156°15'W
[5]Position Represents Location of Trisponder Antenna which is about 15m from the Survey Vessel Stern

PLUME SURVEY

OTEC-1 MIXED-WATER DISCHARGE
11 April 1981

Tow No. 2

Tow Time (HST): 1409-1418 Wire Out (m)[1]: 50

Wire Angle (from Vertical): 30 Depth of Submerged Pump Intake (m): 43

Discharged Flow Conditions

Mixed-Water Discharge Flow Rate (gpm):	155,420
Injected Dye Flow Rate (gpm):	0.0666
Calculated Dye Concentration in Mixed-Water Discharge[2] (ppm):	0.429
Mixed-Water Discharge Temperature (°F):	64.5

Data from Ocean Energy Converter at 1411 HST

Heading (°T): 247 , Current Speed (cm/sec): 26.7 , Current Direction (°M): 44.7

Plume Data:

Maximum Fluorometer Reading:	14
Maximum Calculated Dye Concentration (ppm):	0.008
Calculated Dilution of Maximum Concentration:	54
Elapse Time of Plume Dye Readings (sec):	45
Approximate Travel Distance Across Dyed Plume (m):	21
Distance from Discharge Point to Plume (m)	95

Original Mixed-Water Discharge Location of Dye Reading[3,4]: x_0(m) = 10,200
y_0(m) = 12,760

SURVEY VESSEL LOCATION DATA

Time (HST)	Survey Vessel Position[4,5] x(m)	y(m)	Position of Survey Vessel Relative To Discharge Location x_0,y_0 x(m)	y(m)
1410	10,243	12,834	43	74
1411	10,270	12.821	70	61
1412	10,304	12,790	104	30
1413	10,325	12,768	125	8
1414	10,333	12,741	133	-19
1415	10,323	12,703	123	-57
1416	10,321	12,687	121	-73

[1]0 Reading at the Water Surface
[2]Dye Flow Rate/Mixed-Water Discharge Flow Rate
[3]The Original Mixed-Water Discharge Location is Obtained by Back Integrating from the Dye Reading Position using Current Speed and Direction to Obtain the Position of the Discharge Location from which the Measured Dye Water was Discharged
[4]An Arbitrary x,y Coordinate System has been Established Centered at Latitude 19°50'N, Longitude 156°15'W
[5]Position Represents Location of Trisponder Antenna which is about 15m from the Survey Vessel Stern

PLUME SURVEY

OTEC-1 MIXED-WATER DISCHARGE
11 April 1981

Tow No. 3 NO DYE FOUND

Tow Time (HST): 1424-1432 Wire Out (m)[1]: 50

Wire Angle (from Vertical): 25° Depth of Submerged Pump Intake (m): 45

Discharged Flow Conditions

Mixed-Water Discharge Flow Rate (gpm):	155,420
Injected Dye Flow Rate (gpm):	0.0666
Calculated Dye Concentration in Mixed-Water Discharge[2] (ppm):	0.429
Mixed-Water Discharge Temperature (°F):	64.5

Data from Ocean Energy Converter at 1425 HST

Heading (°T): 249, Current Speed (cm/sec): 32.9, Current Direction (°M): 25.8

Plume Data:

Maximum Fluorometer Reading:	
Maximum Calculated Dye Concentration (ppm):	
Calculated Dilution of Maximum Concentration:	NO
Elapse Time of Plume Dye Readings (sec):	DYE
Approximate Travel Distance Across Dyed Plume (m):	READINGS
Distance from Discharge Point to Plume (m)	

Original Mixed-Water Discharge Location of Dye Reading[4,5]: x_0(m) = 10,263
y_0(m) = 12,596

SURVEY VESSEL LOCATION DATA

Time (HST)	Survey Vessel Position[5,6] x(m)	y(m)	Position of Survey Vessel Relative To Discharge Location x_0,y_0 x(m)	y(m)
1424	10,440	12,677	177	81
1425	10,445	12,721	182	125
1426	10,436	12,764	173	168
1427	10,434	12,812	171	216
1428	10,430	12,864	167	268
1429	10,433	12,921	170	325
1430	10,416	12,957	153	361
1431	10,416	13,009	153	413

[1]0 Reading at the Water Surface
[2]Dye Flow Rate/Mixed-Water Discharge Flow Rate
[3]The Original Mixed-Water Discharge Location is Obtained by Back Integrating from the Dye Reading Position using Current Speed and Direction to Obtain the Position of the Discharge Location from which the Measured Dye Water was Discharged
[4]An Arbitrary x,y Coordinate System has been Established Centered at Latitude 19°50'N, Longitude 156°15'W
[5]Position Represents Location of Trisponder Antenna which is about 15m from the Survey Vessel Stern

PLUME SURVEY

OTEC-1 MIXED-WATER DISCHARGE
11 April 1981

Tow No. 4

Tow Time (HST): 1442-1452 Wire Out (m)[1]: 50

Wire Angle (from Vertical): 45 Depth of Submerged Pump Intake (m): 35

Discharged Flow Conditions

Mixed-Water Discharge Flow Rate (gpm):	155,420
Injected Dye Flow Rate (gpm):	0.0666
Calculated Dye Concentration in Mixed-Water Discharge[2] (ppm):	0.429
Mixed-Water Discharge Temperature (°F):	64.5

Data from Ocean Energy Converter at 1448 HST

Heading (°T): 254 , Current Speed (cm/sec): 28.7, Current Direction (°M): 37.8

Plume Data:

Maximum Fluorometer Reading:	10
Maximum Calculated Dye Concentration (ppm):	0.006
Calculated Dilution of Maximum Concentration:	75
Elapse Time of Plume Dye Readings (sec):	77
Approximate Travel Distance Across Dyed Plume (m):	99
Distance from Discharge Point to Plume (m)	290

Original Mixed-Water Discharge Location of Dye Reading[4,5]: x_0(m) = 10,268
y_0(m) = 12,583

SURVEY VESSEL LOCATION DATA

Time (HST)	Survey Vessel Position[5,6] x(m)	y(m)	Position of Survey Vessel Relative To Discharge Location x_0,y_0 x(m)	y(m)
1447	10,333	12,783	65	200
1448	10,411	12,772	143	189
1449	10,488	12,772	220	189
1450	10,550	12,739	282	156
1451	10,642	12,737	374	154
1452	10,708	12,719	440	136

[1]0 Reading at the Water Surface
[2]Dye Flow Rate/Mixed-Water Discharge Flow Rate
[3]The Original Mixed-Water Discharge Location is Obtained by Back Integrating from the Dye Reading Position using Current Speed and Direction to Obtain the Position of the Discharge Location from which the Measured Dye Water was Discharged
[4]An Arbitrary x,y Coordinate System has been Established Centered at Latitude 19°50'N, Longitude 156°15'W
[5]Position Represents Location of Trisponder Antenna which is about 15m from the Survey Vessel Stern

PLUME SURVEY

OTEC-1 MIXED-WATER DISCHARGE
11 April 1981

Tow No. 5 NO DYE FOUND

Tow Time (HST): 1518-1523 Wire Out (m)[1]: 60

Wire Angle (from Vertical): 50 Depth of Submerged Pump Intake (m): 39

Discharged Flow Conditions

Mixed-Water Discharge Flow Rate (gpm):	155,690
Injected Dye Flow Rate (gpm):	0.0666
Calculated Dye Concentration in Mixed-Water Discharge[2] (ppm):	0.428
Mixed-Water Discharge Temperature (°F):	64.4

Data from Ocean Energy Converter at 1523 HST

Heading (°T): 260, Current Speed (cm/sec): 23.0, Current Direction (°M): 353.6

Plume Data:

Maximum Fluorometer Reading:	
Maximum Calculated Dye Concentration (ppm):	
Calculated Dilution of Maximum Concentration:	
Elapse Time of Plume Dye Readings (sec):	NO
Approximate Travel Distance Across Dyed Plume (m):	DYE
Distance from Discharge Point to Plume (m)	FOUND

Original Mixed-Water Discharge Location of Dye Reading[4,5]: x_0(m) = _____
y_0(m) = _____

SURVEY VESSEL LOCATION DATA

Time (HST)	Survey Vessel Position[5,6] x(m)	y(m)	Position of Survey Vessel Relative To Discharge Location x_0,y_0 x(m)	y(m)
1518	10,982	12,510		
1519	10,927	12,528		
1520	10,870	12,545		
1521	10,833	12,551		
1522	10,800	12,553		

[1]0 Reading at the Water Surface
[2]Dye Flow Rate/Mixed-Water Discharge Flow Rate
[3]The Original Mixed-Water Discharge Location is Obtained by Back Integrating from the Dye Reading Position using Current Speed and Direction to Obtain the Position of the Discharge Location from which the Measured Dye Water was Discharged
[4]An Arbitrary x,y Coordinate System has been Established Centered at Latitude 19°50'N, Longitude 156°15'W
[5]Position Represents Location of Trisponder Antenna which is about 15m from the Survey Vessel Stern

PLUME SURVEY

OTEC-1 MIXED-WATER DISCHARGE
11 April 1981

Tow No. 6 NO DYE FOUND

Tow Time (HST): 1524-1550 Wire Out (m)[1]: 70

Wire Angle (from Vertical): 45-50° Depth of Submerged Pump Intake (m): 47

Discharged Flow Conditions

Mixed-Water Discharge Flow Rate (gpm):	155,690
Injected Dye Flow Rate (gpm):	0.0666
Calculated Dye Concentration in Mixed-Water Discharge[2] (ppm):	0.428
Mixed-Water Discharge Temperature (°F):	64.4

Data from Ocean Energy Converter at 1523 HST

Heading (°T): 260 , Current Speed (cm/sec): 23.0 , Current Direction (°M): 353.6

Plume Data:

Maximum Fluorometer Reading:	
Maximum Calculated Dye Concentration (ppm):	
Calculated Dilution of Maximum Concentration:	
Elapse Time of Plume Dye Readings (sec):	NO DYE FOUND
Approximate Travel Distance Across Dyed Plume (m):	
Distance from Discharge Point to Plume (m)	

Original Mixed-Water Discharge Location of Dye Reading[4,5]: x_0(m) = 10,350
y_0(m) = 12,410

SURVEY VESSEL LOCATION DATA

Time (HST)	Survey Vessel Position[5,6] x(m)	y(m)	Position of Survey Vessel Relative To Discharge Location x_0,y_0 x(m)	y(m)
1526	10,822	12,541	472	131
1527	10,804	12,551	454	141
1528	10,768	12,551	418	141
1529	10,750	12,550	400	140
1530	10,713	12,553	363	143
1535	10,578	12,549	228	139
1540	10,453	12,569	103	159
1545	10,340	12,644	-10	234
1549	10,240	12,705	-110	295

[1]0 Reading at the Water Surface
[2]Dye Flow Rate/Mixed-Water Discharge Flow Rate
[3]The Original Mixed-Water Discharge Location is Obtained by Back Integrating from the Dye Reading Position using Current Speed and Direction to Obtain the Position of the Discharge Location from which the Measured Dye Water was Discharged
[4]An Arbitrary x,y Coordinate System has been Established Centered at Latitude 19°50'N, Longitude 156°15'W
[5]Position Represents Location of Trisponder Antenna which is about 15m from the Survey Vessel Stern

PLUME SURVEY

OTEC-1 MIXED-WATER DISCHARGE
11 April 1981

Tow No. 7

Tow Time (HST): 1559-1606 Wire Out (m)[1]: 50

Wire Angle (from Vertical): 55 Depth of Submerged Pump Intake (m): 29

Discharged Flow Conditions

Mixed-Water Discharge Flow Rate (gpm):	156,280
Injected Dye Flow Rate (gpm):	0.0666
Calculated Dye Concentration in Mixed-Water Discharge[2] (ppm):	0.426
Mixed-Water Discharge Temperature (°F):	64.0

Data from Ocean Energy Converter at 1601 HST

Heading (°T): 262, Current Speed (cm/sec): 32.3, Current Direction (°M): 44.6

Plume Data:

Maximum Fluorometer Reading:	45
Maximum Calculated Dye Concentration (ppm):	0.026
Calculated Dilution of Maximum Concentration:	16
Elapse Time of Plume Dye Readings (sec):	66
Approximate Travel Distance Across Dyed Plume (m):	96
Distance from Discharge Point to Plume (m)	140

Original Mixed-Water Discharge Location of Dye Reading[4,5]: x_0(m) = 10,432
y_0(m) = 12,273

SURVEY VESSEL LOCATION DATA

Time (HST)	Survey Vessel Position[5,6] x(m)	y(m)	Position of Survey Vessel Relative To Discharge Location x_0,y_0 x(m)	y(m)
1600	10,415	12,440	-17	167
1601	10,486	12,397	54	124
1602	10,543	12,336	111	63
1603	10,619	12,296	187	23
1604	10,701	12,277	269	4
1605	10,791	12,260	359	-13

[1]0 Reading at the Water Surface
[2]Dye Flow Rate/Mixed-Water Discharge Flow Rate
[3]The Original Mixed-Water Discharge Location is Obtained by Back Integrating from the Dye Reading Position using Current Speed and Direction to Obtain the Position of the Discharge Location from which the Measured Dye Water was Discharged
[4]An Arbitrary x,y Coordinate System has been Established Centered at Latitude 19°50'N, Longitude 156°15'W
[5]Position Represents Location of Trisponder Antenna which is about 15m from the Survey Vessel Stern

PLUME SURVEY

OTEC-1 MIXED-WATER DISCHARGE
11 April 1981

Tow No. 8

Tow Time (HST): 1610-1620 Wire Out (m)[1]: 50

Wire Angle (from Vertical): 55 Depth of Submerged Pump Intake (m): 29

Discharged Flow Conditions

Mixed-Water Discharge Flow Rate (gpm):	156,280
Injected Dye Flow Rate (gpm):	0.0666
Calculated Dye Concentration in Mixed-Water Discharge[2] (ppm):	0.426
Mixed-Water Discharge Temperature (°F):	64.0

Data from Ocean Energy Converter at 1613 HST

Heading (°T): 262 , Current Speed (cm/sec): 25.8 , Current Direction (°M): 52.0

Plume Data:

Maximum Fluorometer Reading:	52
Maximum Calculated Dye Concentration (ppm):	0.03
Calculated Dilution of Maximum Concentration:	14.2
Elapse Time of Plume Dye Readings (sec):	44
Approximate Travel Distance Across Dyed Plume (m):	44
Distance from Discharge Point to Plume (m)	90

Original Mixed-Water Discharge Location of Dye Reading[4,5]: x_0(m) = 10,425
y_0(m) = 12,280

SURVEY VESSEL LOCATION DATA

Time (HST)	Survey Vessel Position[5,6] x(m)	y(m)	Position of Survey Vessel Relative To Discharge Location x_0,y_0 x(m)	y(m)
1614	10,588	12,301	163	21
1615	10,531	12,315	106	35
1616	10,467	12,325	42	45
1617	10,427	12,358	2	78
1618	10,374	12,380	-51	100

[1]0 Reading at the Water Surface
[2]Dye Flow Rate/Mixed-Water Discharge Flow Rate
[3]The Original Mixed-Water Discharge Location is Obtained by Back Integrating from the Dye Reading Position using Current Speed and Direction to Obtain the Position of the Discharge Location from which the Measured Dye Water was Discharged
[4]An Arbitrary x,y Coordinate System has been Established Centered at Latitude 19°50'N, Longitude 156°15'W
[5]Position Represents Location of Trisponder Antenna which is about 15m from the Survey Vessel Stern

PLUME SURVEY

OTEC-1 MIXED-WATER DISCHARGE
11 April 1981

Tow No. 9

Tow Time (HST): 1624-1632 Wire Out (m)[1]: 50

Wire Angle (from Vertical): 55° Depth of Submerged Pump Intake (m): 29

Discharged Flow Conditions

Mixed-Water Discharge Flow Rate (gpm):	156,280
Injected Dye Flow Rate (gpm):	0.0666
Calculated Dye Concentration in Mixed-Water Discharge[2] (ppm):	0.426
Mixed-Water Discharge Temperature (°F):	64.0

Data from Ocean Energy Converter at 1624 HST

Heading (°T): 264 , Current Speed (cm/sec): 41.2 , Current Direction (°M): 0.5

Plume Data:

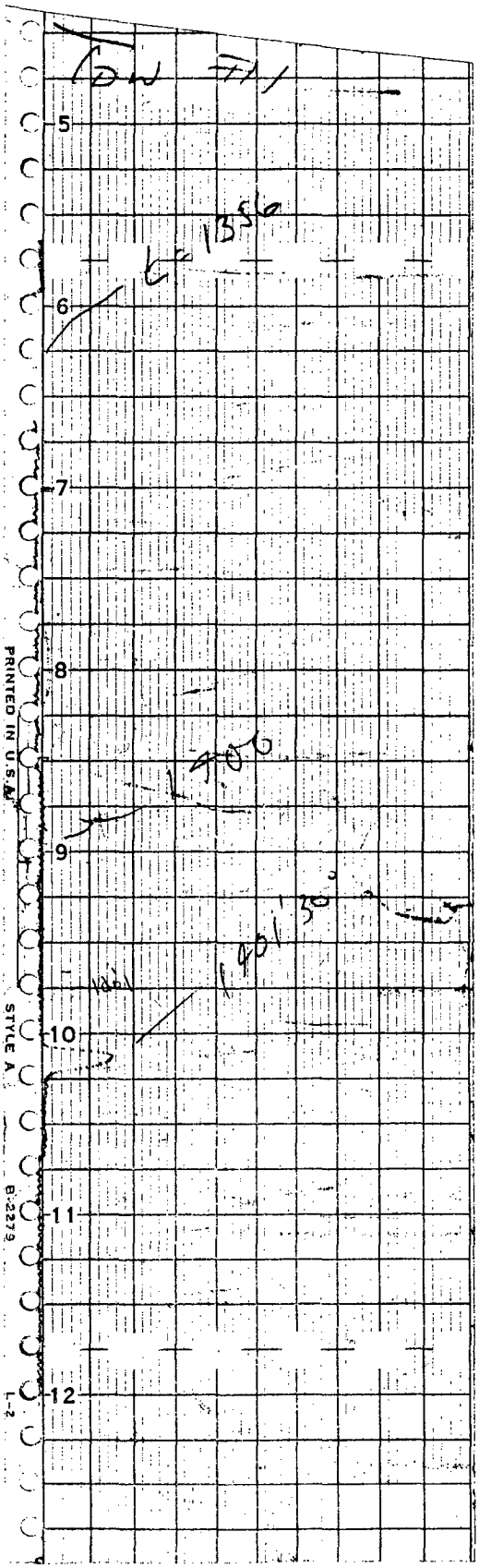
Maximum Fluorometer Reading:	45
Maximum Calculated Dye Concentration (ppm):	0.026
Calculated Dilution of Maximum Concentration:	16.6
Elapse Time of Plume Dye Readings (sec):	40
Approximate Travel Distance Across Dyed Plume (m):	57
Distance from Discharge Point to Plume (m)	75

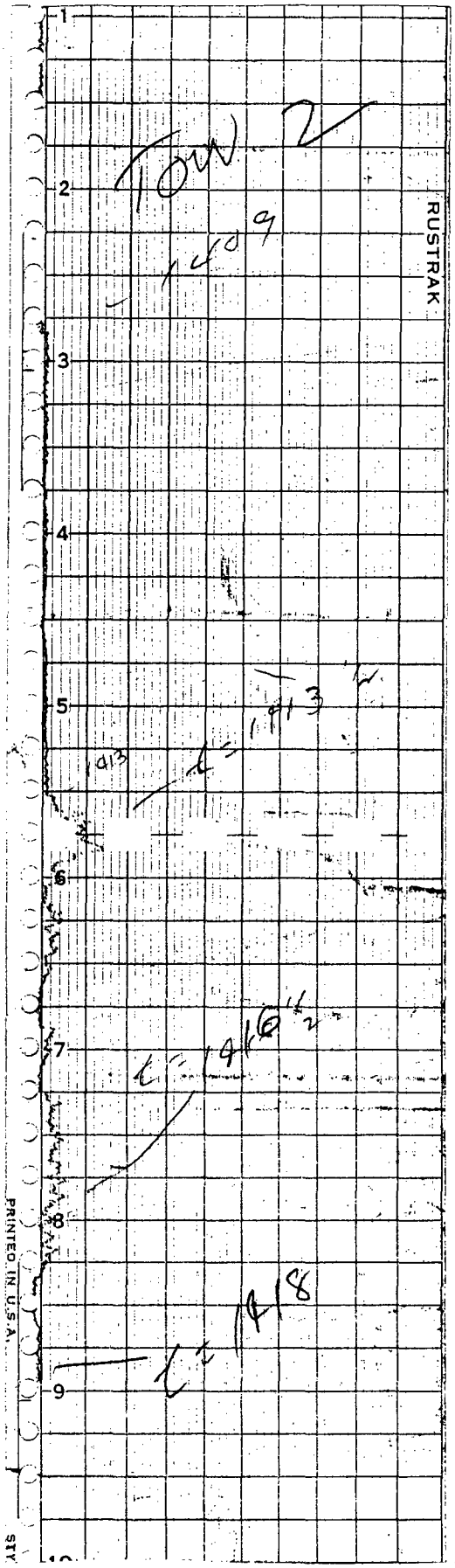
Original Mixed-Water Discharge Location of Dye Reading[4,5]: x_0(m) = 10,482
y_0(m) = 12,205

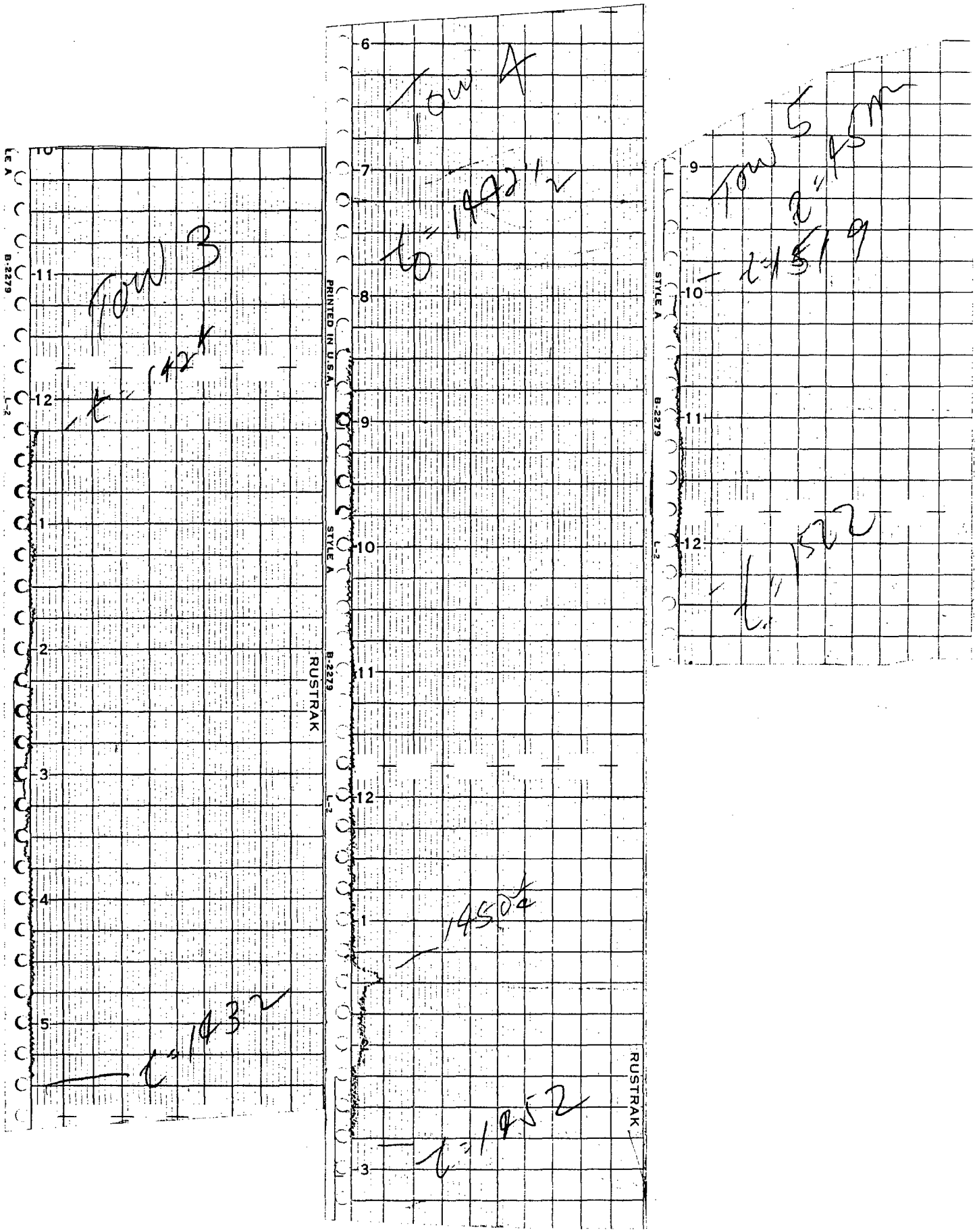
SURVEY VESSEL LOCATION DATA

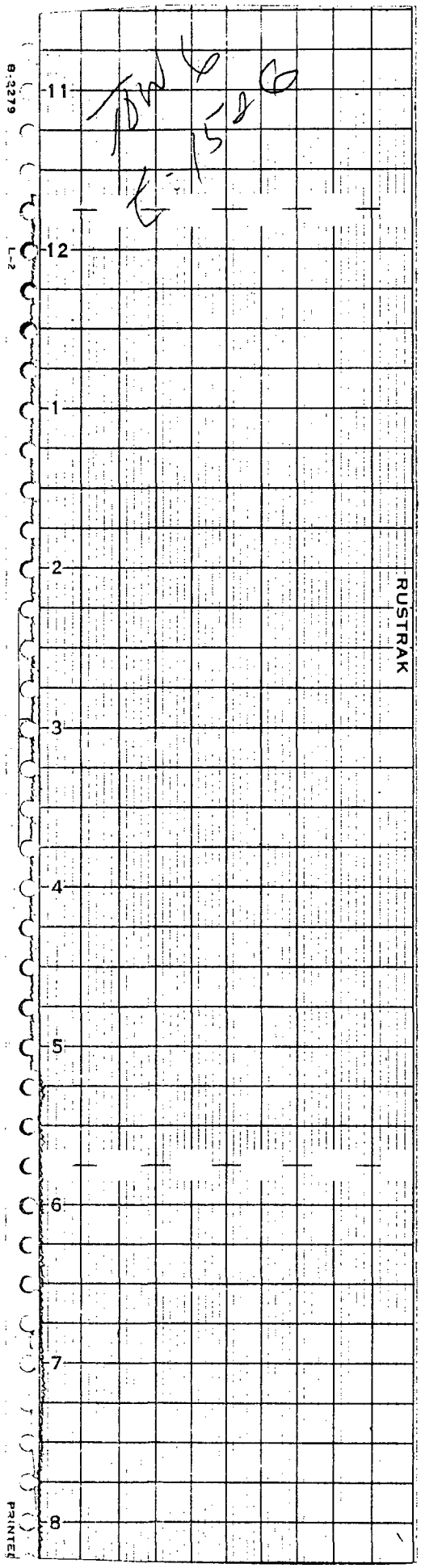
Time (HST)	Survey Vessel Position[5,6] x(m)	y(m)	Position of Survey Vessel Relative To Discharge Location x_0,y_0 x(m)	y(m)
1628	10,506	12,277	24	72
1629	10,567	12,222	85	17
1630	10,642	12,185	160	-20
1631	10,719	12,148	237	-57
1632	10,802	12,124	320	-81

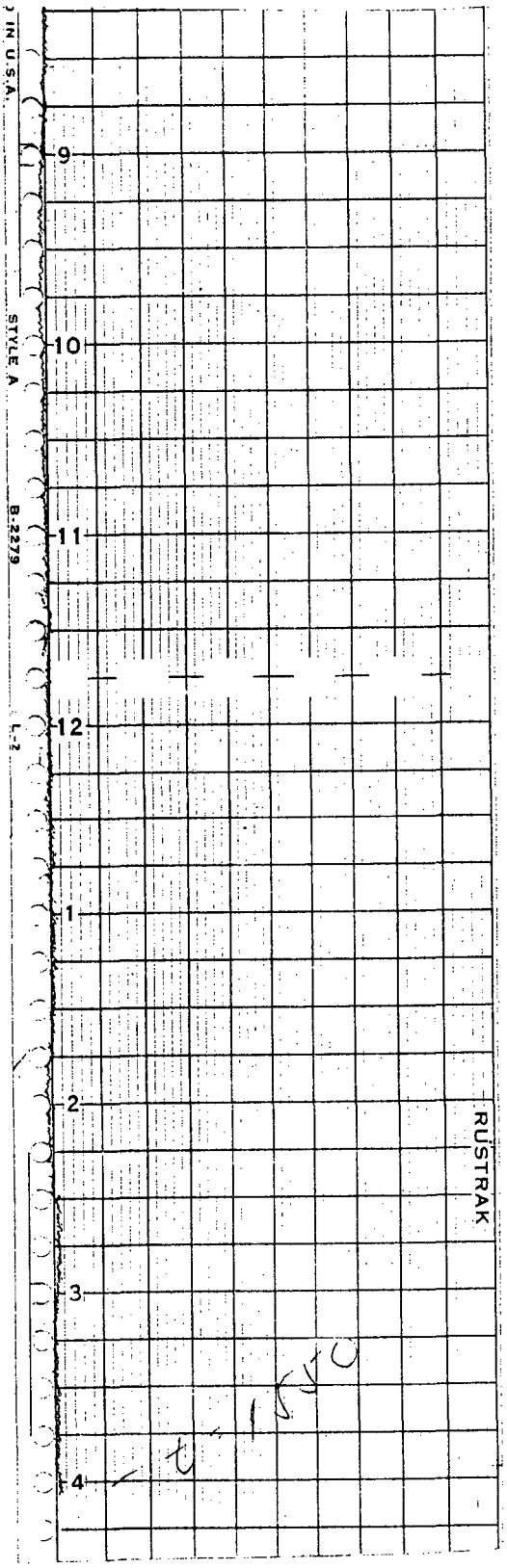
[1]0 Reading at the Water Surface
[2]Dye Flow Rate/Mixed-Water Discharge Flow Rate
[3]The Original Mixed-Water Discharge Location is Obtained by Back Integrating from the Dye Reading Position using Current Speed and Direction to Obtain the Position of the Discharge Location from which the Measured Dye Water was Discharged
[4]An Arbitrary x,y Coordinate System has been Established Centered at Latitude 19°50'N, Longitude 156°15'W
[5]Position Represents Location of Trisponder Antenna which is about 15m from the Survey Vessel Stern

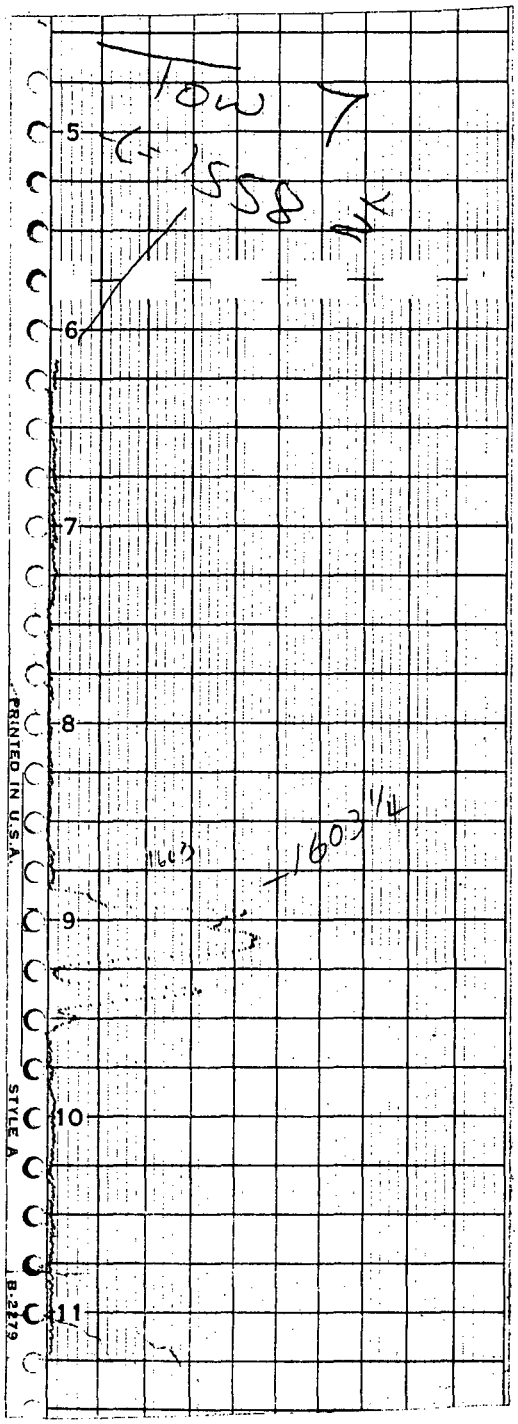

PRINTED IN U.S.A.
STYLE A
B-2279
L-2

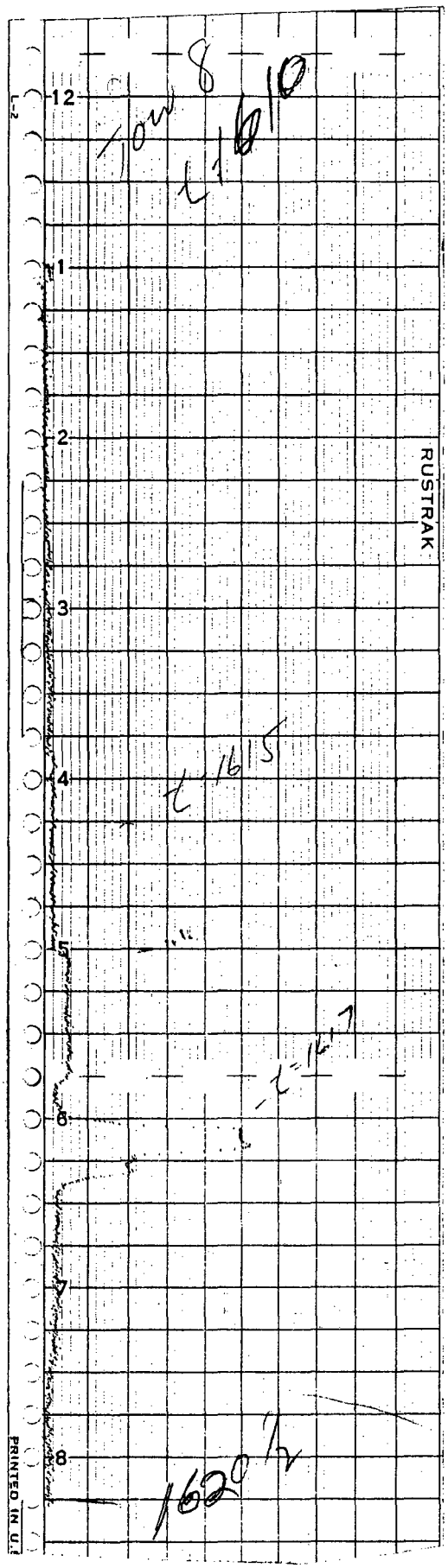

RUSTRAK
PRINTED IN U.S.A.

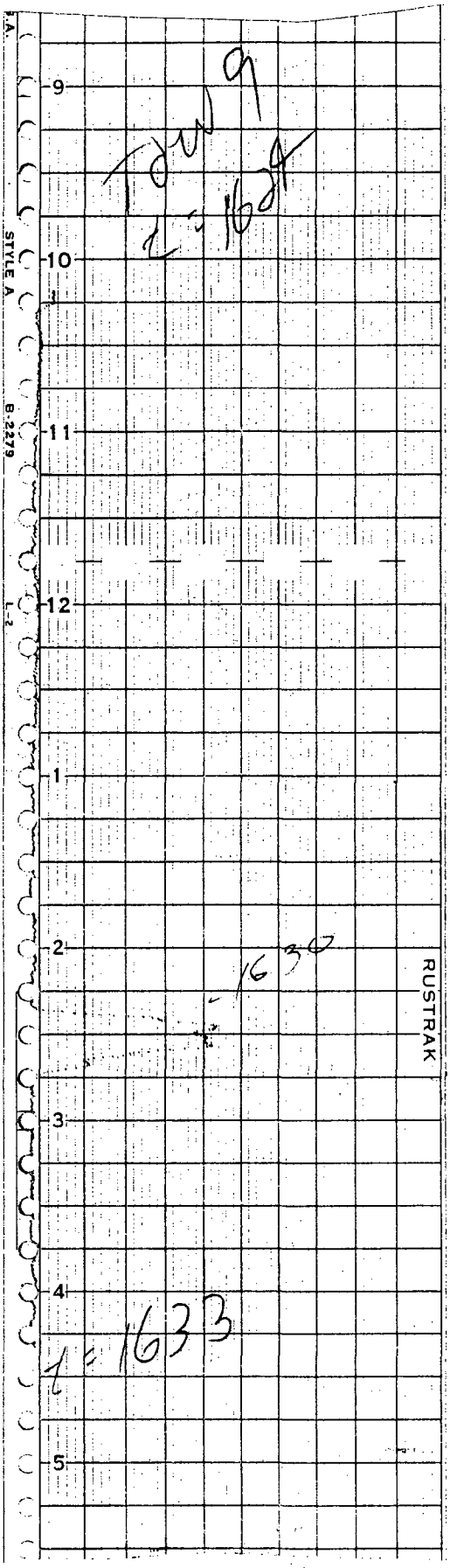

RUSTRAK
STYLE A
B-2279
L-2
PRINTED IN U.S.A.


B-2279
L-2
RUSTRAK
PRINTED


IN U.S.A.
STYLE A
B-2279
L-2
RUSTRAK


PRINTED IN U.S.A.
STYLE A
B-2179


RUSTRAK
PRINTED IN U.S.


STYLE A
B-2279
L-2
9
10
11
12
1
2
3
4
5
RUSTRAK
1633
1630

OTEC-1 PLUME SURVEY

APPENDIX G

CHLOROPHYLL, ATP AND PHAEOPIGMENT DATA

Cruise: HOTEC-12 Plume Survey
Location: In-Plume Data
55m Downstream of Discharge

Ship: M/V El Greco
Date: 12 April 1981
Time: 1033-1050

Depth (m)	Chlorophyll-a (µg/ℓ)	Phaeopigments (µg/ℓ)	P/C	ATP (ng/ℓ)
25	0.073	0.004	0.058	18.61
25	0.064	0.065	1.014	49.44
25	0.092	0.025	0.269	19.44
25	0.069	0.082	1.193	33.05
25	0.050	0.018	0.367	18.33
25	0.101	0.080	0.795	17.77
25	0.064	0.095	1.484	23.61
25	0.092	0.003	0.034	95.00
25	0.023	0.136	5.956	26.66

Cruise: HOTEC-12 Plume Survey
Location: Control Station Data
75m Upstream of Discharge

Ship: M/V El Greco
Date: 12 April 1981
Time: 1800-1830

Depth (m)	Chlorophyll-a (µg/ℓ)	Phaeopigments (µg/ℓ)	P/C	ATP (ng/ℓ)
25	0.087	0.029	0.336	49.20
25	0.073	0.026	0.351	46.57
25	0.073	0.052	0.704	50.79
25	0.069	0.013	0.191	47.09
25	0.073	0.056	0.763	32.85
25	0.096	0.037	0.388	37.07
25	0.059	0.070	1.169	31.26
25	0.092	0.033	0.363	34.96
25	0.092	0.000	0.000	65.04

Cruise: HOTEC-12 Plume Survey
Location: Plume Profile Data
55m Downstream of Discharge

Ship: M/V El Greco
Date: 12 April 1981
Time: 1244-1330

Depth (m)	Chlorophyll-a (µg/ℓ)	Phaeopigments (µg/ℓ)	P/C	ATP (ng/ℓ)
5	0.087	0.012	0.138	25.55
5	0.059	0.078	1.314	29.44
5	0.069	0.022	0.316	38.33
10	0.059	0.087	1.458	23.33
10	0.082	0.017	0.201	30.27
10	0.055	0.087	1.585	31.66
15	0.082	0.042	0.514	30.00
15	0.069	0.082	1.193	31.39
15	0.069	0.086	1.256	26.11
20	0.050	0.109	2.162	53.89
20	0.105	0.028	0.267	26.11
20	0.059	0.074	1.242	32.77
25	0.078	0.030	0.382	30.27
25	0.078	0.030	0.382	35.00
25	0.046	0.057	1.256	26.94
30	0.087	0.120	1.375	30.00
30	0.146	0.021	0.146	33.33
30	0.082	0.098	1.193	18.88
35	0.101	0.084	0.837	50.00
35	0.096	0.175	1.820	134.44
35	0.101	0.084	0.837	36.94
40	0.105	0.088	0.839	40.00
40	0.096	0.085	0.880	39.44
40	0.078	0.111	1.433	40.00
45	0.124	0.001	0.010	92.22
45	0.101	0.149	1.478	38.33
45	0.096	0.110	1.149	50.55

Cruise: HOTEC-12 Plume Survey
Location: Control Station Profile Data
75m Upstream of Discharge

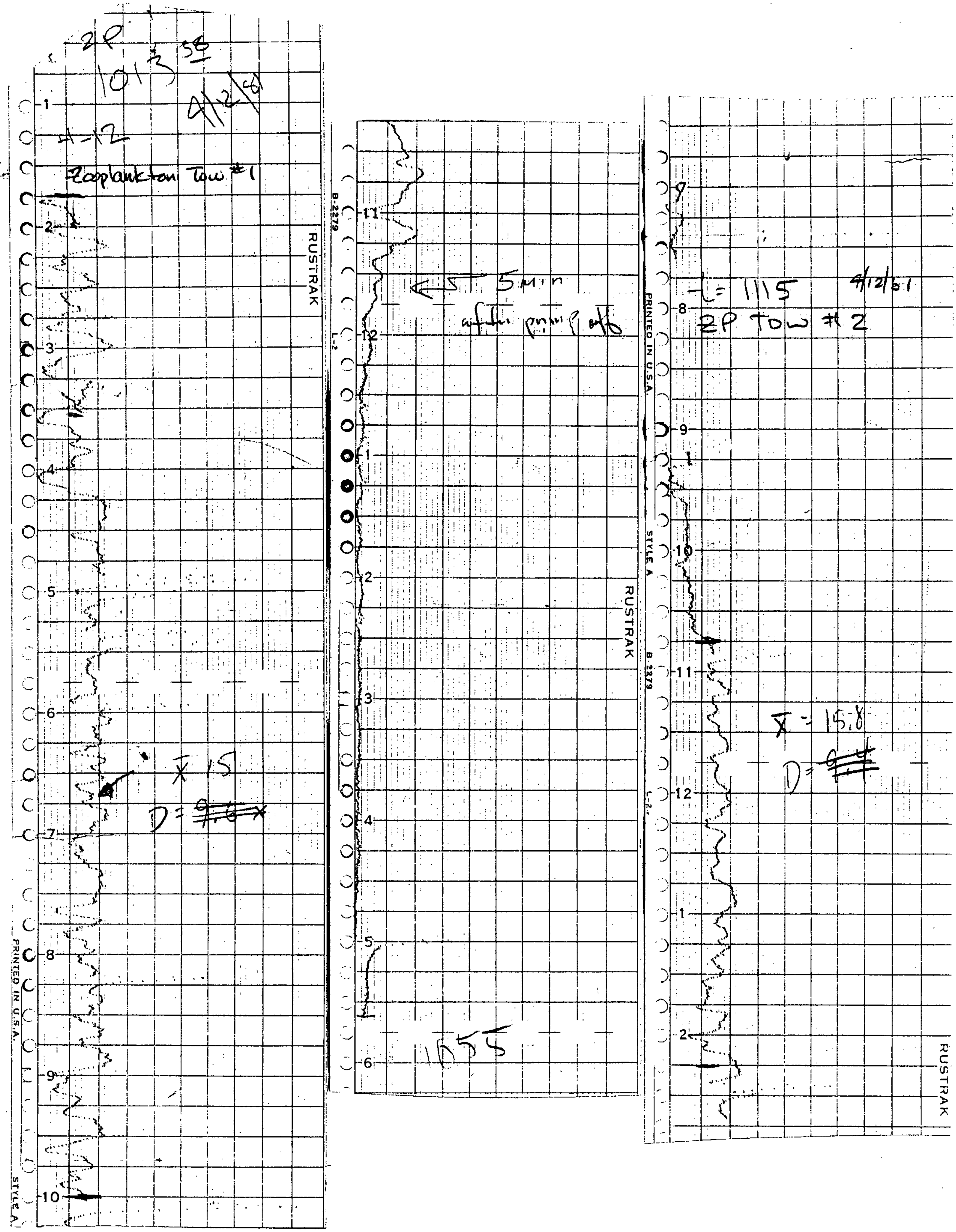
Ship: M/V El Greco
Date: 12 April 1981
Time: 1701-1755

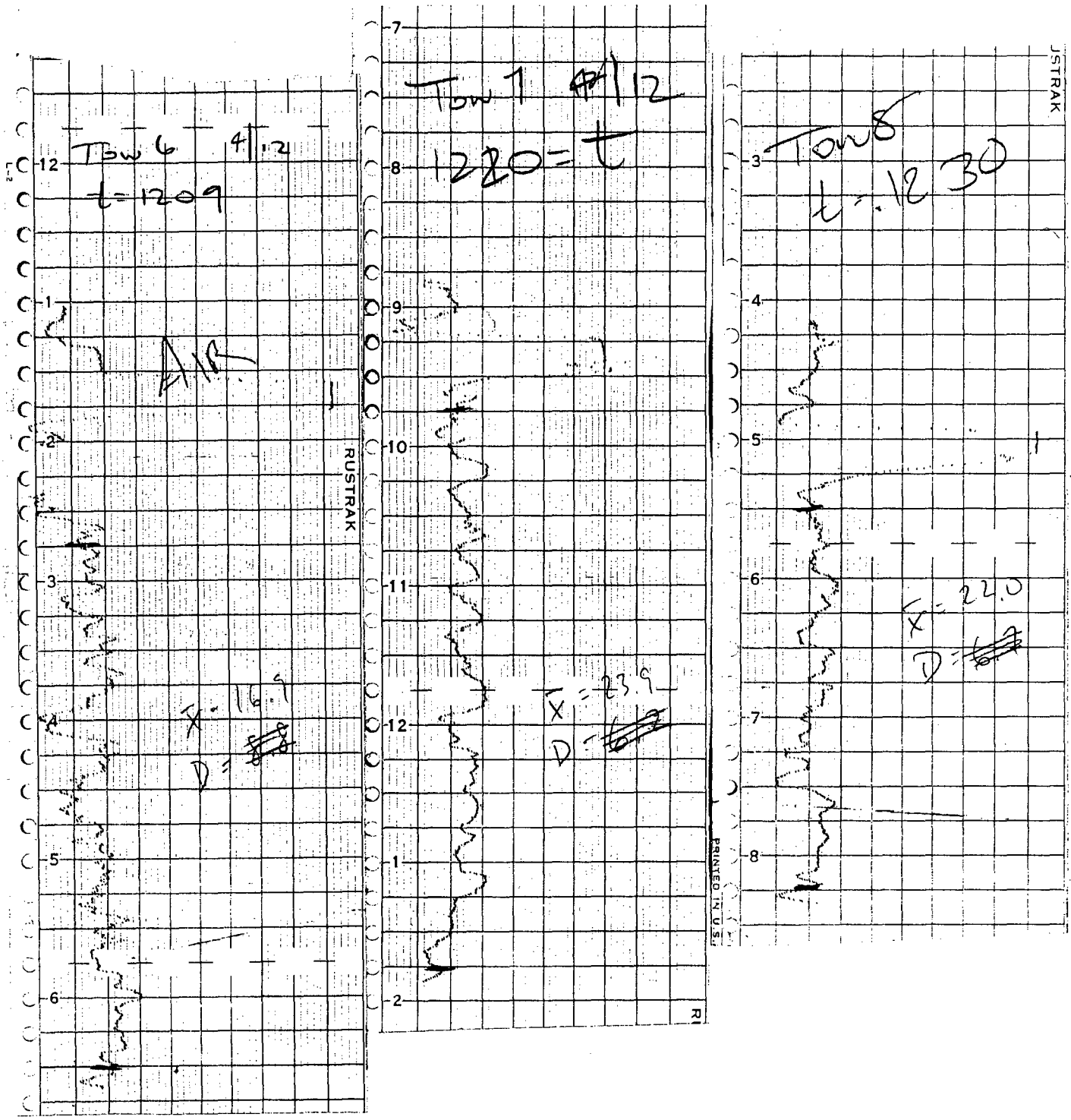
Depth (m)	Chlorophyll-a (µg/ℓ)	Phaeopigments (µg/ℓ)	P/C	ATP (ng/ℓ)
5	0.046	0.075	1.632	93.53
5	0.096	0.046	0.477	38.12
5	0.087	0.008	0.088	40.23
10	0.064	0.065	1.014	43.40
10	0.059	0.095	1.603	39.18
10	0.092	0.000	0.000	41.82
15	0.073	0.090	1.233	41.29
15	0.055	0.087	1.585	46.57
15	0.110	0.002	0.018	50.26
20	0.078	0.000	0.000	42.87
20	0.096	0.011	0.119	38.65
20	0.087	0.064	0.732	41.82
25	0.041	0.131	3.178	44.98
25	0.087	0.021	0.237	47.09
25	0.050	0.087	1.735	47.62
30	0.092	0.059	0.645	113.06
30	0.092	0.033	0.363	58.70
30	0.092	0.016	0.175	66.62
35	0.133	0.001	0.005	48.15
35	0.133	0.022	0.167	44.98
35	0.082	0.064	0.776	50.79
40	0.073	0.064	0.880	42.87
40	0.101	0.050	0.495	59.23
40	0.096	0.085	0.880	42.87
45	0.105	0.054	0.512	94.06
45	0.169	0.000	0.000	46.04
45	0.078	0.086	1.101	52.90

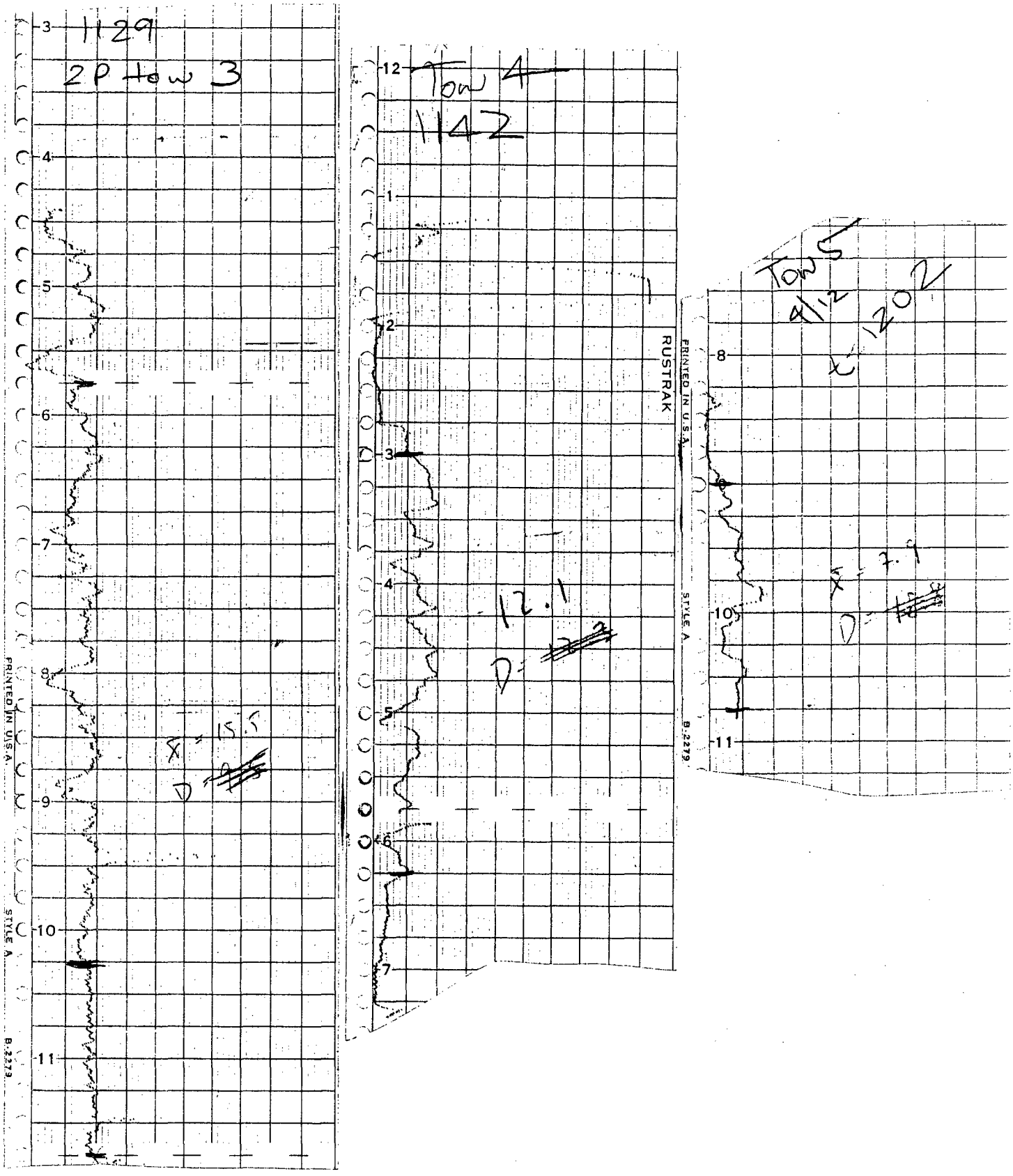
OTEC-1 PLUME SURVEY

APPENDIX H

FLUOROMETER RECORDS DURING PLUME ZOOPLANKTON NET TOWS


ZP
4/12/61
Zooplankton Tow #1
RUSTRAK
PRINTED IN U.S.A.
STYLE A
B-2279
x̄ 15
5 min
after pump off
1155
t = 1115
4/12/61
ZP Tow #2
x̄ = 15.8


Tow 6 4|12
t=1209
AIR
X=16.9
D=
RUSTRAK
Tow 7 #12
1220=t
X=23.9
D=
PRINTED IN U.S.
Tow 8
t=1230
X=22.0
D=
JSTRAK


1129
2P tow 3
X = 15.5
D =
Tow 4
1142
12.1
D =
RUSTRAK
PRINTED IN U.S.A.
STYLE A
B-2279
Tow 5
1202
X = 7.9
D =

OTEC-1 PLUME SURVEY

APPENDIX I

ZOOPLANKTON NET TOW AND COUNT DATA

SITE, CRUISE AND STATION NO.	SAMPLE NO.	POS., LAT. & LONG.	DATE	TIME START D (day) or N (night)	LENGTH OF TOW (min.)	NET TYPE, SIZE, MESH	ACTUAL DEPTHS (m)	AGREES WITH TDR	SAMPLE AND TOW TYPE
HOTEC-12 OEC	PS1	in OTEC-1 plume	12 April 81	1015D	48	75 cm ring 202 µm	-	-	LIVE/DEAD Horizontal Zooplankton
"	PS2	"	"	1115D	6	"	-	-	"
"	PS3	"	"	1130D	9	"	-	-	"
"	PS4	"	"	1142D	10	"	-	-	"
"	PSB1	"	"	1159D	8	"	-	-	BIOMASS Horizontal Zooplankton
"	PSB2	"	"	1208D	8	"	-	-	"
"	PSB3	"	"	1219D	10	"	-	-	"
"	PSB4	"	"	1230D	9	"	-	-	"

SITE, CRUISE AND STATION NO.	SAMPLE NO.	WIRE OUT m	WIRE ANGLE	FLOW METER READINGS	VOL. FIL. m^3	SPLIT SIZE TAXON. ANAL.	SPLIT SIZE DR. WT. ANAL.	FLOW METER CALIBRATION 1 turn = 0.0234 m^3 COMMENTS
HOTEC-12 OEC	PS1	25	<5	676543 654162	524	1	-	All tows taken while moored downstream of OEC, by lowering net into prevailing current.
"	PS2	"	"	652193 647317	114	1	-	PS1-4 stained with neutral red before preservation.
"	PS3	"	"	647308 643125	97.9	1	-	
"	PS4	"	"	643125 639273	90.1	1	-	
"	PSB1	"	"	639273 636593	62.7	3/4	1/4	
"	PSB2	"	"	636593 633293	77.2	"	"	
"	PSB3	"	"	633293 629148	97.0	"	"	
"	PSB4	"	"	629148 625442	86.7	"	"	

SITE, CRUISE AND STATION NO.	SAMPLE NO.	WIRE OUT m	WIRE ANGLE	FLOW METER READINGS	VOL. FIL. m^3	SPLIT SIZE TAXON. ANAL.	SPLIT SIZE DR. WT. ANAL.	FLOW METER CALIBRATION 1 turn = 0.0234 m^3 COMMENTS
HOTEC-12 OEC	OP1	25	<5	610638 606894	87.5	1	-	All tows taken while moored upstream of OEC, by lowering net into prevailing current. OP1-4 stained with neutral red before preservation.
"	OP2	"	"	606894 603690	75.0	1	-	
"	OP3	"	"	603684 600619	71.7	1	-	
"	OP4	"	"	600619 597746	67.2	1	-	
"	OPB1	"	"	625418 621719	86.6	3/4	1/4	
"	OPB2	"	"	621729 617908	89.4	"	"	
"	OPB3	"	"	617898 614470	80.2	"	"	
"	OPB4	"	"	614465 610638	89.6	"	"	

SITE, CRUISE AND STATION NO.	SAMPLE NO.	POS., LAT. & LONG.	DATE	TIME START D (day) or N (night)	LENGTH OF TOW (min.)	NET TYPE, SIZE, MESH	ACTUAL DEPTHS (m)	AGREES WITH TDR	SAMPLE AND TOW TYPE
HOTEC-12 OEC	OP1	Out of OTEC-1 Plume	12 Apr 81	1514D	9	75 cm ring 202 µm	-	-	LIVE/DEAD Horizontal Zooplankton
"	OP2	"	"	1526D	9	"	--	-	"
"	OP3	"	"	1536D	9	"	-	-	"
"	OP4	"	"	1546D	9	"	-	-	"
"	OPB1	"	"	1430D	8	"	-	-	BIOMASS Horizontal Zooplankton
"	OPB2	"	"	1441D	9	"	-	-	"
"	OPB3	"	"	1452D	5	"	-	-	"
"	OPB4	"	"	1503	9	"	-	-	"

MACROPLANKTON DATA FOR HOTEC-12 PLUME SAMPLES, APR 1981

SAMPLE ID : PSB-1
HORIZONTAL TOW IN PLUME AT 25 METERS, 200 MICRON MESH NET
12APR1981 11:59
TOW DURATION = 8 MINUTES
VOLUME SAMPLED = 62.7, SUBSAMPLE PRESERVED = 3 /4

TAXON	COUNT	ALIQUOT	NUMBER PER 100 CU. M.
FORAMINIFERA	23	0.0500	978
RADIOLARIA	102	0.0500	4340
ECHINODERM LARVA	2	0.0500	85
MEDUSA	1	0.0500	42
SIPHONOPHORE	1	0.0500	42
GASTROPOD VELIGER	5	0.0500	213
PELECYPOD VELIGER	2	0.0500	85
POLYCHAETE	3	0.0500	128
EVADNE SP.	2	0.0500	85
AMPHIPOD	2	0.0500	85
EUPHAUSIID	5	0.0500	213
CHAETOGNATH	4	0.0500	170
LARVACEAN	169	0.0500	7190
SALP	3	0.0500	128
FISH EGG	253	0.0500	10800
EGGS	8	0.0500	340
UNIDENTIFIED LARVA	2	0.0500	85
COPEPODS			
COPEPOD NAUPLIUS	3	0.0500	128
SMALL JUVENILE CALANOID	64	0.0500	2720
LARGE JUVENILE CALANOID	44	0.0500	1870
CALANOID COPEPOD	2	0.0500	85
MECYNOCERA CLAUSI	12	0.0500	510
ACROCALANUS SP.	6	0.0500	255
PARACALANUS SP.	3	0.0500	128
CLAUSOCALANUS SP.	40	0.0500	1700
CALOCALANUS PLUMULOSUS	8	0.0500	340
EUCHAETA MARINA	3	0.0500	128
SCOLECITHRIX SP.	1	0.0500	42
LUCICUTIA SP.	1	0.0500	42
ACARTIA NEGLIGENS	17	0.0500	723
OITHONA SP.	38	0.0500	1620
CORYCAEIDAE	33	0.0500	1400
ONCAEA SP.	33	0.0500	1400
COPILIA SP.	1	0.0500	42

TOTAL TAXA COUNTED = 34
TOTAL ANIMALS COUNTED = 896
TOTAL PER 100 CUBIC METERS = 38145

MACROPLANKTON DATA FOR HOTEC-12 PLUME SAMPLES, APR 1981

SAMPLE ID : PSB-2
HORIZONTAL TOW IN PLUME AT 25 METERS, 200 MICRON MESH NET
12APR1981 12:08
TOW DURATION = 8 MINUTES
VOLUME SAMPLED = 77.2, SUBSAMPLE PRESERVED = 3 /4

TAXON	COUNT	ALIQUOT	NUMBER PER 100 CU. M.
FORAMINIFERA	13	0.0167	1350
RADIOLARIA	5	0.0167	518
MEDUSA	1	0.0167	104
SIPHONOPHORE	3	0.0167	311
GASTROPOD VELIGER	3	0.0167	311
POLYCHAETE	2	0.0167	207
EUPHAUSIID	2	0.0167	207
CHAETOGNATH	4	0.0167	415
LARVACEAN	90	0.0167	9330
SALP	1	0.0167	104
FISH LARVA	1	0.0167	104
FISH EGG	110	0.0167	11400
EGGS	2	0.0167	207
UNIDENTIFIED LARVA	1	0.0167	104
COPEPODS			
SMALL JUVENILE CALANOID	73	0.0333	3780
LARGE JUVENILE CALANOID	14	0.0333	725
CALANOID COPEPOD	12	0.0333	622
NEOCALANUS ROBUSTIOR	4	0.0333	207
MECYNOCERA CLAUSI	5	0.0333	259
ACROCALANUS SP.	5	0.0333	259
PARACALANUS SP.	3	0.0333	155
CLAUSOCALANUS SP.	34	0.0333	1760
CALOCALANUS PAVO	6	0.0333	311
CALOCALANUS PLUMULOSUS	2	0.0333	104
EUCHAETA MARINA	11	0.0333	570
SCOLECITHRIX SP.	5	0.0333	259
LUCICUTIA SP.	1	0.0333	52
ACARTIA NEGLIGENS	18	0.0333	933
OITHONA SP.	22	0.0333	1140
CORYCAEIDAE	46	0.0333	2380
ONCAEA SP.	30	0.0333	1550
COPILIA SP.	1	0.0333	52

TOTAL TAXA COUNTED = 32
TOTAL ANIMALS COUNTED = 530
TOTAL PER 100 CUBIC METERS = 39790

MACROPLANKTON DATA FOR HOTEC-12 PLUME SAMPLES, APR 1981

SAMPLE ID : PSB-3
HORIZONTAL TOW IN PLUME AT 25 METERS, 200 MICRON MESH NET
12APR1981 12:19
TOW DURATION = 10 MINUTES
VOLUME SAMPLED = 97.0, SUBSAMPLE PRESERVED = 3 /4

TAXON	COUNT	ALIQUOT	NUMBER PER 100 CU. M.
FORAMINIFERA	20	0.0167	1650
RADIOLARIA	40	0.0167	3300
SIPHONOPHORE	4	0.0167	330
GASTROPOD VELIGER	1	0.0167	82
PELECYPOD VELIGER	1	0.0167	82
EUPHAUSIID	4	0.0167	330
CHAETOGNATH	1	0.0167	82
LARVACEAN	79	0.0167	6520
SALP	5	0.0167	412
FISH LARVA	1	0.0167	82
FISH EGG	112	0.0167	9240
EGGS	4	0.0167	330
COPEPODS			
COPEPOD NAUPLIUS	2	0.0333	82
SMALL JUVENILE CALANOID	108	0.0333	4450
LARGE JUVENILE CALANOID	9	0.0333	371
CALANOID COPEPOD	13	0.0333	536
NEOCALANUS ROBUSTIOR	1	0.0333	41
MECYNOCERA CLAUSI	7	0.0333	289
ACROCALANUS SP.	10	0.0333	412
PARACALANUS SP.	4	0.0333	165
CLAUSOCALANUS SP.	61	0.0333	2520
CALOCALANUS PAVO	2	0.0333	82
CALOCALANUS PLUMULOSUS	5	0.0333	206
EUCHAETA MARINA	7	0.0333	289
SCOLECITHRIX SP.	5	0.0333	206
LUCICUTIA SP.	1	0.0333	41
CANDACIA SP.	2	0.0333	82
ACARTIA NEGLIGENS	15	0.0333	619
OITHONA SP.	45	0.0333	1860
CORYCAEIDAE	27	0.0333	1110
ONCAEA SP.	51	0.0333	2100

TOTAL TAXA COUNTED = 31
TOTAL ANIMALS COUNTED = 647
TOTAL PER 100 CUBIC METERS = 37905

MACROPLANKTON DATA FOR HOTEC-12 PLUME SAMPLES, APR 1981

SAMPLE ID : PSB-4
HORIZONTAL TOW IN PLUME AT 25 METERS, 200 MICRON MESH NET
12APR1981 12:30
TOW DURATION = 9 MINUTES
VOLUME SAMPLED = 86.7, SUBSAMPLE PRESERVED = 3 /4

TAXON	COUNT	ALIQUOT	NUMBER PER 100 CU. M.
FORAMINIFERA	17	0.0167	1570
RADIOLARIA	37	0.0167	3410
ECHINODERM LARVA	1	0.0167	92
MEDUSA	3	0.0167	277
GASTROPOD VELIGER	2	0.0167	185
PELECYPOD VELIGER	2	0.0167	185
POLYCHAETE	3	0.0167	277
CHAETOGNATH	5	0.0167	461
LARVACEAN	80	0.0167	7380
FISH EGG	136	0.0167	12500
EGGS	9	0.0167	830
COPEPODS			
COPEPOD NAUPLIUS	1	0.0333	46
SMALL JUVENILE CALANOID	102	0.0333	4710
LARGE JUVENILE CALANOID	9	0.0333	415
CALANOID COPEPOD	11	0.0333	507
NEOCALANUS ROBUSTIOR	2	0.0333	92
MECYNOCERA CLAUSI	12	0.0333	554
ACROCALANUS SP.	7	0.0333	323
PARACALANUS SP.	3	0.0333	138
CLAUSOCALANUS SP.	41	0.0333	1890
CALOCALANUS PAVO	5	0.0333	231
EUCHAETA MARINA	7	0.0333	323
SCOLECITHRIX SP.	1	0.0333	46
CANDACIA SP.	3	0.0333	138
ACARTIA NEGLIGENS	17	0.0333	784
OITHONA SP.	30	0.0333	1380
CORYCAEIDAE	35	0.0333	1610
ONCAEA SP.	44	0.0333	2030
COPILIA SP.	1	0.0333	46

TOTAL TAXA COUNTED = 29
TOTAL ANIMALS COUNTED = 626
TOTAL PER 100 CUBIC METERS = 42431

MACROPLANKTON DATA FOR HOTEC-12 PLUME SAMPLES, APR 1981

SAMPLE ID : OPB-1
HORIZONTAL TOW OUT OF PLUME AT 25 METERS, 200 MICRON MESH NET
12APR1981 14:30
TOW DURATION = 8 MINUTES
VOLUME SAMPLED = 86.6, SUBSAMPLE PRESERVED = 3 /4

TAXON	COUNT	ALIQUOT	NUMBER PER 100 CU. M.
FORAMINIFERA	10	0.0167	924
RADIOLARIA	27	0.0167	2490
ECHINODERM LARVA	1	0.0167	92
MEDUSA	2	0.0167	185
SIPHONOPHORE	1	0.0167	92
GASTROPOD VELIGER	8	0.0167	739
PELECYPOD VELIGER	3	0.0167	277
EUPHAUSIID	5	0.0167	462
CHAETOGNATH	2	0.0167	185
LARVACEAN	80	0.0167	7390
SALP	2	0.0167	185
FISH EGG	104	0.0167	9610
EGGS	2	0.0167	185
UNIDENTIFIED LARVA	3	0.0167	277
COPEPODS			
COPEPOD NAUPLIUS	1	0.0167	92
SMALL JUVENILE CALANOID	115	0.0167	10600
LARGE JUVENILE CALANOID	12	0.0167	1110
CALANOID COPEPOD	10	0.0167	924
NEOCALANUS ROBUSTIOR	7	0.0167	647
ACROCALANUS SP.	6	0.0167	554
PARACALANUS SP.	4	0.0167	370
CLAUSOCALANUS SP.	60	0.0167	5540
CALOCALANUS PLUMULOSUS	9	0.0167	831
EUCHAETA MARINA	11	0.0167	1020
SCOLECITHRIX SP.	1	0.0167	92
LUCICUTIA SP.	2	0.0167	185
ACARTIA NEGLIGENS	3	0.0167	277
OITHONA SP.	32	0.0167	2960
CORYCAEIDAE	12	0.0167	1110
ONCAEA SP.	18	0.0167	1660

TOTAL TAXA COUNTED = 30
TOTAL ANIMALS COUNTED = 553
TOTAL PER 100 CUBIC METERS = 51067

MACROPLANKTON DATA FOR HOTEC-12 PLUME SAMPLES, APR 1981

SAMPLE ID : OP8-2
HORIZONTAL TOW OUT OF PLUME AT 25 METERS, 200 MICRON MESH NET
12APR1981 14:41
TOW DURATION = 9 MINUTES
VOLUME SAMPLED = 89.4, SUBSAMPLE PRESERVED = 3 /4

TAXON	COUNT	ALIQUOT	NUMBER PER 100 CU. M.
FORAMINIFERA	3	0.0125	358
RADIOLARIA	35	0.0125	4180
ECHINODERM LARVA	1	0.0125	119
MEDUSA	1	0.0125	119
SIPHONOPHORE	4	0.0125	477
GASTROPOD VELIGER	7	0.0125	835
PELECYPOD VELIGER	4	0.0125	477
AMPHIPOD	1	0.0125	119
EUPHAUSIID	3	0.0125	358
CRAB LARVA	1	0.0125	119
CHAETOGNATH	5	0.0125	597
LARVACEAN	91	0.0125	10900
SALP	1	0.0125	119
FISH EGG	70	0.0125	8350
EGGS	8	0.0125	955
UNIDENTIFIED LARVA	3	0.0125	358
COPEPODS			
SMALL JUVENILE CALANOID	106	0.0125	12600
LARGE JUVENILE CALANOID	32	0.0125	3820
CALANOID COPEPOD	8	0.0125	955
NEOCALANUS ROBUSTIOR	11	0.0125	1310
MECYNOCERA CLAUSI	3	0.0125	358
ACROCALANUS SP.	2	0.0125	239
PARACALANUS SP.	4	0.0125	477
CLAUSOCALANUS SP.	80	0.0125	9550
CALOCALANUS PAVO	1	0.0125	119
CALOCALANUS PLUMULOSUS	3	0.0125	358
EUCHAETA MARINA	9	0.0125	1070
SCOLECITHRIX SP.	5	0.0125	597
LUCICUTIA SP.	1	0.0125	119
ACARTIA NEGLIGENS	5	0.0125	597
OITHONA SP.	30	0.0125	3580
CORYCAEIDAE	7	0.0125	835
ONCAEA SP.	15	0.0125	1790

TOTAL TAXA COUNTED = 33
TOTAL ANIMALS COUNTED = 560
TOTAL PER 100 CUBIC METERS = 66814

MACROPLANKTON DATA FOR HOTEC-12 PLUME SAMPLES, APR 1981

SAMPLE ID : OPB-3
HORIZONTAL TOW OUT OF PLUME AT 25 METERS, 200 MICRON MESH NET
12APR1981 14:52
TOW DURATION = 5 MINUTES
VOLUME SAMPLED = 80.2, SUBSAMPLE PRESERVED = 3 /4

TAXON	COUNT	ALIQUOT	NUMBER PER 100 CU. M.
FORAMINIFERA	6	0.0250	399
RADIOLARIA	43	0.0250	2860
ECHINODERM LARVA	5	0.0250	333
SIPHONOPHORE	2	0.0250	133
GASTROPOD VELIGER	7	0.0250	466
PELECYPOD VELIGER	3	0.0250	200
POLYCHAETE	1	0.0250	66
AMPHIPOD	1	0.0250	66
EUPHAUSIID	7	0.0250	466
CHAETOGNATH	3	0.0250	200
LARVACEAN	101	0.0250	6720
SALP	1	0.0250	66
FISH EGG	144	0.0250	9580
EGGS	7	0.0250	466
UNIDENTIFIED LARVA	1	0.0250	66
COPEPODS			
COPEPOD NAUPLIUS	1	0.0125	133
SMALL JUVENILE CALANOID	79	0.0125	10500
LARGE JUVENILE CALANOID	9	0.0125	1200
CALANOID COPEPOD	12	0.0125	1600
NEOCALANUS ROBUSTIOR	2	0.0125	266
MECYNOCERA CLAUSI	3	0.0125	399
ACROCALANUS SP.	3	0.0125	399
PARACALANUS SP.	1	0.0125	133
CLAUSOCALANUS SP.	91	0.0125	12100
CALOCALANUS PAVO	2	0.0125	266
CALOCALANUS PLUMULOSUS	5	0.0125	665
EUCHAETA MARINA	12	0.0125	1600
LUCICUTIA SP.	1	0.0125	133
CANDACIA SP.	4	0.0125	532
ACARTIA NEGLIGENS	2	0.0125	266
OITHONA SP.	6	0.0125	798
CORYCAEIDAE	11	0.0125	1460
ONCAEA SP.	9	0.0125	1200

TOTAL TAXA COUNTED = 33
TOTAL ANIMALS COUNTED = 585
TOTAL PER 100 CUBIC METERS = 55739

MACROPLANKTON DATA FOR HOTEC-12 PLUME SAMPLES, APR 1981

SAMPLE ID : OP8-4
HORIZONTAL TOW OUT OF PLUME AT 25 METERS, 200 MICRON MESH NET
12APR1981 15:03
TOW DURATION = 9 MINUTES
VOLUME SAMPLED = 89.6, SUBSAMPLE PRESERVED = 3 /4

TAXON	COUNT	ALIQUOT	NUMBER PER 100 CU. M.
FORAMINIFERA	10	0.0250	595
RADIOLARIA	45	0.0250	2680
ECHINODERM LARVA	5	0.0250	298
SIPHONOPHORE	1	0.0250	59
PTEROPOD	2	0.0250	119
GASTROPOD VELIGER	17	0.0250	1010
PELECYPOD VELIGER	7	0.0250	417
EUPHAUSIID	8	0.0125	952
CHAETOGNATH	2	0.0125	238
LARVACEAN	116	0.0125	13800
FISH EGG	151	0.0125	18000
EGGS	14	0.0125	1670
UNIDENTIFIED LARVA	4	0.0125	476
COPEPODS			
COPEPOD NAUPLIUS	1	0.0125	119
SMALL JUVENILE CALANOID	100	0.0125	11900
LARGE JUVENILE CALANOID	15	0.0125	1790
CALANOID COPEPOD	3	0.0125	357
NEOCALANUS ROBUSTIOR	5	0.0125	595
MECYNOCERA CLAUSI	5	0.0125	595
PARACALANUS SP.	1	0.0125	119
CLAUSOCALANUS SP.	76	0.0125	9050
CALOCALANUS PAVO	2	0.0125	238
CALOCALANUS PLUMULOSUS	4	0.0125	476
EUCHAETA MARINA	11	0.0125	1310
SCOLECITHRIX SP.	3	0.0125	357
CANDACIA SP.	2	0.0125	238
ACARTIA NEGLIGENS	3	0.0125	357
OITHONA SP.	12	0.0125	1430
CORYCAEIDAE	6	0.0125	714
ONCAEA SP.	18	0.0125	2140

TOTAL TAXA COUNTED = 30
TOTAL ANIMALS COUNTED = 649
TOTAL PER 100 CUBIC METERS = 72099

OTEC-1 PLUME SURVEY

APPENDIX J

WATER QUALITY DATA

Cruise: HOTEC-12 Plume Survey
Location: In-Plume Data
55m Downstream of Discharge

Ship: M/V El Greco
Date: 12 April 1981
Time: 1033-1050 HST

Depth (m)	Temperature (°C)	Salinity (o/oo)	pH	Total Alkalinity (meq/ℓ)	Total CO_2 (milimoles/ℓ)	Specific Alkalinity
25	24.25	34.792	8.310	2.261	1.884	0.117
25	24.25	34.784	8.308	2.261	1.885	0.117
25	24.25	34.784	8.305	2.270	1.895	0.118
25	24.25	34.772	8.301	2.261	1.890	0.117
25	24.25	34.788	8.298	2.258	1.890	0.117
25	24.25	34.792	8.305	2.261	1.888	0.117
25	24.25	34.768	8.300	2.273	1.902	0.118
25	24.25	34.796	8.306	2.270	1.894	0.118
25	24.25	34.796	8.310	2.273	1.896	0.118

Cruise: HOTEC-12 Plume Survey
Location: Control Station Data
75m Upstream of Discharge

Ship: M/V El Greco
Date: 12 April 1981
Time: 1800-1830 HST

Depth (m)	Temperature (°C)	Salinity (o/oo)	pH	Total Alkalinity (meq/ℓ)	Total CO_2 (milimoles/ℓ)	Specific Alkalinity
25	24.40	34.768	8.291	2.276	1.907	0.118
25	24.40	34.784	8.292	2.261	1.893	0.117
25	24.40	34.784	8.292	2.255	1.887	0.117
25	24.40	34.780	8.292	2.264	1.895	0.118
25	24.40	34.772	8.294	2.273	1.902	0.118
25	24.40	34.772	8.293	2.261	1.892	0.117
25	24.40	34.784	8.294	2.267	1.897	0.118
25	24.40	34.776	8.294	2.273	1.902	0.118
25	24.40	34.752	8.293	2.255	1.887	0.117
25	24.40	34.792	8.293	2.267	1.897	0.118

Cruise: HOTEC-12 Plume Survey
Location: Control Station Plume Data
75m Upstream of Discharge

Ship: M/V El Greco
Date: 12 April 1981
Time: 1701-1755 HST

Depth (m)	Ortho Phosphates (µg-at/ℓ)	Nitrates & Nitrites (µg-at/ℓ)	Ammonium (µg-at/ℓ)	Silicates (µg-at/ℓ)	Total Soluble Phosphorus (µg-at/ℓ)	Total Soluble Nitrogen (µg-at/ℓ)
5	0.15	0.01	0.46	1.52	0.385	4.67
5	0.14	0.01	0.46	1.90	0.385	4.04
5	0.14	0.01	0.46	1.33	0.385	4.64
10	0.14	0.01	0.50	1.33	0.385	4.97
10	0.14	0.01	0.46	1.33	0.385	5.08
10	0.14	0.01	0.46	1.33	0.385	4.68
15	0.14	0.01	0.48	1.33	0.370	4.58
15	0.15	0.01	0.52	1.33	0.370	5.72
15	0.15	0.05	0.50	1.33	0.370	4.76
20	0.12	0.05	0.44	0.38	0.385	4.73
20	0.14	0.05	0.48	1.52	0.385	4.62
20	0.14	0.10	0.48	1.33	0.385	4.48
25	0.12	0.05	0.50	1.70	0.354	3.00
25	0.12	0.05	0.50	1.71	0.339	3.81
25	0.12	0.05	0.50	1.51	0.354	3.92
30	0.12	0.05	0.50	1.51	0.370	4.12
30	0.08	0.10	0.48	2.45	0.277	5.08
30	0.12	0.10	0.57	1.70	0.354	4.03
35	0.15	0.10	0.59	3.59	0.385	4.30
35	0.06	0.10	0.31	0.94	0.246	3.79
35	0.15	0.10	0.55	2.45	0.385	4.33
40	0.15	0.05	0.63	1.89	0.385	4.54
40	0.26	0.98	0.81	44.06*	0.447	7.97
40	0.18	0.10	0.59	2.26	0.385	4.83
45	0.17	0.10	0.59	1.70	0.370	4.51
45	0.17	0.10	0.65	1.70	0.370	4.58
45	0.09	0.16	0.46	2.45	0.185	3.55

*Data excluded

Cruise: HOTEC-12 Plume Survey
Location: Plume Profile Data
55m Downstream of Discharge

Ship: M/V El Greco
Date: 12 April 1981
Time: 1244-1330 HST

Depth (m)	Ortho Phosphates (µg-at/ℓ)	Nitrates & Nitrites (µg-at/ℓ)	Ammonium (µg-at/ℓ)	Silicates (µg-at/ℓ)	Total Soluble Phosphorus (µg-at/ℓ)	Total Soluble Nitrogen (µg-at/ℓ)
5	0.14	0.10	0.52	1.52	0.377	3.81
5	0.14	0.05	0.50	1.52	0.393	4.15
5	0.14	0.10	0.55	1.71	0.393	4.02
10	0.14	0.10	0.52	1.71	0.393	4.17
10	0.15	0.16	0.52	2.66	0.393	4.24
10	0.14	0.16	0.52	1.90	0.393	4.11
15	0.15	0.47	0.52	2.28	0.408	4.42
15	0.08	0.47	0.33	1.71	0.298	4.18
15	0.15	0.52	0.50	2.28	0.408	4.63
20	0.17	0.62	0.55	2.47	0.408	5.44
20	0.15	0.41	0.50	2.09	0.408	5.29
20	0.17	0.67	0.50	2.66	0.440	5.65
25	0.17	0.73	0.46	2.66	0.424	5.65
25	0.17	0.67	0.48	2.66	0.424	5.38
25	0.17	0.57	0.46	2.47	0.424	5.34
30	0.17	0.57	0.50	2.47	0.424	5.61
30	0.14	0.10	0.50	1.71	0.408	5.09
30	0.09	0.10	0.39	1.71	0.298	4.81
35	0.15	0.10	0.52	1.71	0.393	4.40
35	0.15	0.10	0.52	1.71	0.393	3.73
35	0.15	0.10	0.52	1.71	0.493	2.61
40	0.15	0.10	0.52	1.71	0.400	3.43
40	0.15	0.10	0.52	1.71	0.400	3.37
40	0.14	0.10	0.52	1.33	0.400	3.69
45	0.14	0.10	0.48	1.71	0.370	3.69
45	0.14	0.10	0.50	1.52	0.370	3.75
45	0.15	0.10	0.50	1.52	0.385	4.39

Cruise: HOTEC-12 Plume Survey
Location: Plume Profile Data
55m Downstream of Discharge

Ship: M/V El Greco
Date: 12 April 1981
Time: 1244-1330 HST

Depth (m)	Temperature (°C)	Salinity (o/oo)	pH	Total Alkalinity (meq/ℓ)	Total CO_2 (milimoles/ℓ)	Specific Alkalinity
5	24.40	34.768	8.345	2.249	1.850	0.117
5	24.40	34.784	8.345	2.252	1.853	0.117
5	24.40	34.764	8.345	2.264	1.864	0.118
10	24.40	34.764	8.340	2.279	1.880	0.118
10	24.40	34.760	8.330	2.270	1.879	0.118
10	24.40	34.776	8.330	2.264	1.874	0.118
15	24.40	34.725	8.317	2.276	1.893	0.118
15	24.40	34.756	8.318	2.270	1.887	0.118
15	24.40	34.729	8.316	2.267	1.886	0.118
20	24.30	34.748	8.311	2.264	1.887	0.118
20	24.30	34.745	8.313	2.264	1.886	0.118
20	24.30	34.701	8.313	2.267	1.889	0.118
25	24.25	34.745	8.307	2.258	1.884	0.117
25	24.25	34.741	8.301	2.264	1.894	0.118
25	24.25	34.745	8.310	2.267	1.893	0.118
30	24.25	34.803	8.306	2.279	1.905	0.118
30	24.25	34.906	8.291	2.273	1.908	0.118
30	24.25	34.886	8.303	2.270	1.898	0.118
35	24.00	34.882	8.299	2.267	1.900	0.117
35	24.00	34.898	8.297	2.273	1.906	0.118
35	24.00	34.886	8.297	2.276	1.909	0.118
40	24.00	34.925	8.293	2.285	1.918	0.118
40	24.00	34.914	8.291	2.282	1.917	0.118
40	24.00	34.925	8.290	2.288	1.923	0.118
45	23.80	34.949	8.289	2.292	1.928	0.118
45	23.80	34.925	8.288	2.280	1.918	0.118
45	23.80	34.925	8.286	2.277	1.917	0.118

Cruise: HOTEC-12 Plume Survey
Location: Control Station Profile Data
75m Upstream of Discharge
Ship: M/V El Greco
Date: 12 April 1981
Time: 1701-1755 HST

Depth (m)	Temperature (°C)	Salinity (o/oo)	pH	Total Alkalinity (meq/ℓ)	Total CO_2 (milimoles/ℓ)	Specific Alkalinity
5	24.60	34.772	8.283	2.279	1.913	0.118
5	24.60	34.756	8.282	2.291	1.925	0.119
5	24.60	34.768	8.286	2.279	1.911	0.118
10	24.50	34.776	8.286	2.270	1.904	0.118
10	24.50	34.760	8.282	2.264	1.901	0.118
10	24.50	34.776	8.279	2.276	1.913	0.118
15	24.50	34.756	8.283	2.270	1.906	0.118
15	24.50	34.760	8.282	2.267	1.904	0.118
15	24.50	34.760	8.284	2.264	1.900	0.118
20	24.40	34.772	8.282	2.279	1.915	0.118
20	24.40	34.776	8.286	2.279	1.913	0.118
20	24.40	34.748	8.290	2.267	1.899	0.118
25	24.40	34.796	8.286	2.282	1.914	0.118
25	24.40	34.780	8.286	2.273	1.907	0.118
25	24.40	34.796	8.287	2.267	1.901	0.118
30	24.20	34.835	8.285	2.273	1.908	0.118
30	24.20	34.835	8.287	2.279	1.912	0.118
30	24.20	34.835	8.288	2.282	1.914	0.118
35	23.80	34.882	8.271	2.276	1.922	0.118
35	23.80	34.894	8.269	2.288	1.934	0.118
35	23.80	34.886	8.271	2.285	1.930	0.118
40	23.50	34.882	8.265	2.291	1.941	0.119
40	23.50	34.902	8.262	2.282	1.935	0.118
40	23.50	34.898	8.265	2.291	1.941	0.119
45	23.25	34.917	8.270	2.291	1.940	0.119
45	23.25	34.917	8.268	2.282	1.933	0.118
45	23.25	34.914	8.269	2.282	1.932	0.118

OTEC-1 PLUME SURVEY

APPENDIX K

CALIBRATION PROCEDURES

Calibration Data for Fluorometric Dye Measurements

While aboard the OEC (10 April 1981) a sample of the Rhodamine WT Dye was collected, and a series of several dilutions prepared for subsequent calibration of the fluorometer. This is a documentation of that procedure. All serial dilutions were made with automatic, volumetric pipettes, and the fluorometric readings were assessed on multiplier 10X using the discrete sample door.

Description of Dilution Series -1

Tube #	Volumetric Addition	Dilution (D)	Dilution Factor (1/D)
67	0.25 ml Dye to 10 ml FSW	1:41	$2.439 \cdot 10^{-2}$
65	0.20 ml 67 to 10 ml FSW	1:(41·51)	$4.782 \cdot 10^{-4}$
66	0.20 ml 65 to 10 ml FSW	1:(41·51·51)	$9.377 \cdot 10^{-6}$
62	0.20 ml 66 to 10 ml FSW	1:(41·51·51·51)	$1.839 \cdot 10^{-7}$

Sample 62 was in the range of detection by the Turner 111 fluorometer; the dilution series 1:(41·51·51·51) = $1:5.439 \cdot 10^{6}$ and this ratio is $1.839 \cdot 10^{-7}$ or 0.1839 ppm. To calibrate the conversion factor for the dye readings, this sample, containing 0.1839 ppm, is measured and the reading used as the denominator, e.g. 0.1839/reading = Factor, having units of "ppm per fluorometric unit" on multiplier 10; this factor times the fluorometric reading of the samples in question gives the sample concentration in ppm.

A replicate dilution series was also conducted. This second series also began with sample 67, but used a different series of volumetric additions.

Description of Dilution Series -2

(see next page)

Description of Dilution Series -2

Tube #	Volumetric Addition	Dilution (D)	Dilution Factor (1/D)
67	0.25 ml Dye to 10 ml FSW	1:41	$2.439 \cdot 10^{-2}$
44	0.5 ml 67 to 9.5 ml FSW	1:(41·20)	$1.220 \cdot 10^{-3}$
43	0.5 ml 44 to 9.5 ml FSW	1:(41·20·20)	$6.098 \cdot 10^{-5}$
42	0.5 ml 43 to 9.5 ml FSW	1:(41·20·20·20)	$3.049 \cdot 10^{-6}$
41	0.5 ml 42 to 9.5 ml FSW	1:(41·20·20·20·20)	$1.524 \cdot 10^{-7}$

Eight different calibration runs were performed on various preparations from both series. The conversion factors from these eight trials averaged 0.00135 ppm per F unit and the standard deviation was 0.00016 ppm/F unit. The value 0.00135 was therefore used to calculate ppm from the sample readings.

All dye results were forwarded separately to Ed Noda on 24 April 1981.

Calibration Procedures for Fluorometric Determination of Chlorophyll a and Phaeopigments

The fluorometric procedures are standardized against the spectrophotometric method for extracted pigments, as described in Strickland and Parsons (1972).

Beginning with pure chlorophyll a (Sigma Chemical Co.), a standard solution in 90% spectral grade acetone was prepared. The extract was assayed spectrophotometrically, and the amount of chlorophyll present calculated according to the trichromatic equations presented in Strickland and Parsons (1972). The same extracts, and dilutions therof, were then read on the fluorometer with door openings 3, 10 and 30.

For each door, the factor F_D, relating fluorescence to pigment concentration, was then calculated. The standardization procedure for phaeopigments requires, in addition, the determination of the fluorescence of the standard extract after acidification with two drops 5% H Cl to a fluorometer cuvette. The equations for calculating phaeopigments use the door factors, F_D, determined as above, and the ratio of the fluorescence reading of the standard extract before and after acidification (designated "T" in the equations).

The T factor for the instrument is 1.94 and the F_D factors for the 3X, 10X, and 30X multipliers are $1.178 \cdot 10^{-4}$, $4.411 \cdot 10^{-5}$, and $1.400 \cdot 10^{-5}$, respectively.

Standardization Procedures for ATP Determination

Solutions of ATP, in six concentrations (0 to 30 ng ATP · ml extract^{-1}), are prepared in TRIS buffer, and analyzed before and after sets of unknown samples. The ATP stock, salts for buffer preparation, and firefly lantern extract, are obtained from Sigma Chemical Company. Equations relating the readings from the ATP photometer to standard concentrations are obtained by regression analysis of the combined standard data run before and after the samples.

For this study, the plume and control samples were analyzed as two sets, each with its own set of standards. The standard curves, also found in Appendices C and D, are:

Plume samples:

$$\text{ATP (ng} \cdot \text{ml extract}^{-1}) = 0.0117 \times (\text{reading}) + 0.116$$

$$n = 13,\ r = 0.990$$

Control samples:

$$\text{ATP (ng} \cdot \text{ml extract}^{-1}) = 0.0111 \times (\text{reading}) - 0.084$$

$$n = 13,\ r = 0.999$$

Raw data for the standard curves follow:

Standard ATP Concentration ng · ml extract^{-1}	Control Sample Set Readings: Before	After	Plume Sample Set Before	After
ø	10	9	9	5
0.5	30	39	39	35
1.0	78	100	100	35
3.0	270	320	320	210
5.0	450	-	-	370
10.0	900	975	975	750
30.0	2600	2800	2800	2240

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720