The Scripps Institution of Oceanography

MARINE TECHNICIANS HANDBOOK

THERMOMETRY

Available from:
Institute of Marine Resources
P. O. Box 109
La Jolla, California 92037

IMR TR-24
Sea Grant Publication No. 17

The Scripps Institution of Oceanography

MARINE TECHNICIANS HANDBOOK

THERMOMETRY

Available from:
Institute of Marine Resources
P. O. Box 109
La Jolla, California 92037

IMR TR-24
Sea Grant Publication No. 17

GENERAL INTRODUCTION

This publication is one of a series intended to provide explicit instructions for the collection of oceanographic data and samples at sea. Individual chapters are being issued separately so that they may be made available as they are prepared and may be replaced by updated versions without replacing the entire series. It can, therefore, be considered as an open-ended "marine technician's handbook".

For many years there have been such manuals in existence within various groups at the Scripps Institution of Oceanography for internal use. These manuals are being updated, and new ones are being prepared where no satisfactory ones existed; they will be issued as they are ready.

The instructions on physical, biological, and chemical oceanographic data collection and processing have been prepared by members of the Data Collection and Processing Group (DCPG), part of the Marine Life Research Group of Scripps. They cover procedures used by that group. Other chapters on geological and geophysical techniques are based on the "Marine Technician's Handbook" series originally prepared by Mr. Frederick S. Dixon, and issued by the Oceanic Research Division some years ago. It is expected that chapters on techniques used by other groups within Scripps will be added.

Since the sections will be published individually, there will undoubtedly be some repetition. This should not detract from the overall purpose of the manual, since it is expected that a single section will be the only one needed for a particular operation. We do not wish to suggest that the methods described are the only methods; we have merely attempted to describe the methods and procedures which we use and which we have found to be reliable and up-to-date. As new information becomes available, attempts are made to test techniques, incorporate them into routine procedures, and then revise the chapter concerned.

In the final analysis the reliability and quality of the data obtained is in your hands. It is imperative that meticulous attention be given to details to insure reliability and usefulness in the results you obtain.

While we have attempted to be thorough in descriptions of techniques, this cannot be considered to be a complete "cookbook" for the novice. It is in most cases assumed that the reader has some prior knowledge and training in the field concerned. We hope, however, that these instructions can serve as a training aid for the novice marine technician, a "cookbook" for the scientist who is taking his own observations, and a reference manual for the experienced technician.

Preparation of these chapters over the years has been supported by the University of California and by grants and contracts from the many federal agencies to the Scripps Institution of Oceanography and to the Institute of Marine Resources. Support for preparation of this more complete and revised manual has come from the National Sea Grant Program.

This Thermometry section of the Marine Technician's Handbook was compiled by Walter Bryan. The material presented has evolved over many years and many DCPG technicians have made contributions. Frances Wilkes and Arnold Mantyla have made significant contributions.

G. G. Shor, Jr.
Sea Grant Program Manager

Thermometry
January 3, 1972

This work is a result of research sponsored by NOAA Office of Sea Grant, Department of Commerce, under Grant #USDC 2-35208. The U.S. Government is authorized to produce and distribute reprints for governmental purposes notwithstanding any copyright notation that may appear hereon.

THERMOMETRY

I. Kinds of Thermometers

- A. Deep sea reversing
- B. Bucket
- C. Sling psychrometer

II. Deep Sea Reversing Thermometers (DSRT)

- A. Protected
- B. Unprotected

III. Use of Protected and Unprotected Thermometers

- A. Thermometer arrangement sheet, (TAS)
- B. Preparing Nansen bottles and thermometers for casts
- C. Cast work
- D. Reading thermometers
    - 1. Procedure
    - 2. Acceptable reading tolerances
        - (a) Shallow casts
        - (b) Deep casts
- E. Malfunctions
    - 1. Types
    - 2. Correcting malfunctions

IV. Processing Deep Sea Reversing Thermometer Data

- A. Protected
- B. Unprotected
- C. Depth computation
- D. Preparation for desk computer processing

V. Calibration of Deep Sea Reversing Thermometers

- A. Definition of temperature
- B. Standard thermometers
- C. Calibration tank
- D. Viewing system
- E. Calibration procedure

1. Index (scale) calibration
2. Auxiliary thermometer calibration
3. V_o calibration

VI. "Q" Values for Unprotected Deep Sea Reversing Thermometers

A. Instructions for a "Q" cast
B. Processing the data

I. Kinds of Thermometers

Three types of mercury-in-glass thermometers are used for temperature measurements at sea:

A. Deep Sea Reversing Thermometers (DSRT)

Cost:	$150 to $175
Accuracy:	About ± 0.02°C, some to ± 0.003°C
Use:	To measure temperature or pressure at any ocean depth.

B. Bucket thermometers

Cost:	$9
Accuracy:	± 0.1°C
Use:	To measure surface temperature

C. Sling psychrometer thermometers

Cost:	$3
Accuracy:	About ± 0.5°C
Use:	To measure "wet" and "dry" temperatures for computation of relative humidity.

II. Deep Sea Reversing Thermometers

A. Protected - A DSRT is composed of two thermometers, a main and an auxiliary. The main is a double-ended thermometer having a large reservoir at one end and a small bulb (smaller reservoir) at the other, joined by a capillary [see Figures 1 and 2]. In the "set position" mercury fills the large reservoir, the capillary, and part of the small bulb. When reversed a constriction (appendix) at the top of the capillary breaks the thread of mercury. The mercury runs into the small bulb, filling it, and part of the capillary. This fixes the *in situ* temperature. Readings are made with a magnifying lens system mounted on a flashlight.

Mounted beside the main thermometer is a conventional thermometer called the auxiliary. It is read in conjunction with the main and indicates the ambient temperature at the time of reading. Usually the temperature in the lab differs from the temperature at which the main was reversed. This information is needed to correct for the expansion (or contraction) that has taken place in the main thermometer since reversal.

The protected thermometer system is completely enclosed in a sealed glass shell, protecting it from the effects of pressure.

B. Unprotected - The unprotected thermometer [see Figure 1] is similar to the protected thermometer, except that one end of the glass shell is open. This allows sea water to compress the reservoir, driving the mercury column higher as pressure (depth) increases.

The unprotected is used in conjunction with the protected thermometer for determining the depth at which the Nansen bottle reversed.

III. Use of Protected and Unprotected Thermometers

A. Thermometer Arrangement Sheet, (TAS) - Each cruise is supplied with a Thermometer Arrangement Sheet (TAS) which indicates the vertical order in which the thermometers are to be used [see sample Form #1]. This original arrangement takes into account such things as anticipated temperatures and depths in the area to be worked. Any deviation from this arrangement requires understanding of thermometer characteristics, oceanographic conditions and processing requirements and should be made by experienced personnel only.

B. Preparing Nansen bottles and thermometers for casts - Thermometers are installed in the Nansen bottles as prescribed by the TAS. They are put into the thermometer rack with the large reservoir at the top. The scales should be in reading position at this time. THE SERIAL NUMBERS OF THE NANSEN BOTTLES MUST NOW BE RECORDED ON THE TAS.

C. Cast work - Before lowering each Nansen bottle in the hydrocast, each thermometer should be checked to insure that it is "set". The small bulb should be about half full of mercury as indicated in Figure 2. If the bulb is full of mercury, or if the upper part of the bulb contains mercury, shake the thermometer up and down in the frame. This should drain the bulb; but if it does not, note the deficiency on the Form 2.5 [see sample Form #2] and continue with the cast. Under no circumstances should the Nansen bottle be hit on the side to loosen the mercury.

When the entire cast has been lowered, a minimum of five minutes is required for the thermometers to come to equilibrium with the surrounding water.

D. Reading thermometers

1. Procedure - When the cast is aboard, a waiting period of 15 minutes is necessary for the thermometers to stabilize to lab temperature. They are then read by two readers, the results being recorded on Form 2.5. The senior observer reads first. After reading thermometers on about five bottles, the readers rotate, the second reader reading the same thermometers.

2. Acceptable reading tolerances - The first reader is responsible for verifying that the readings are within acceptable limits. Reread any that are not. The limits are as follows:

(a) Shallow casts (1500 meters or less)

± 0.03°C on unprotected thermometers etched in 1/5°C

± 0.02°C on all others

An additional 0.01°C is allowed for each 0.5°C change in the auxiliary provided both main and auxiliary are higher, or both are lower than the values of the first reader. The main thermometers should be read to the nearest 0.01°C, and the auxiliaries to 0.1°C, unless otherwise instructed.

(b) Deep casts

Etching interval	Read to	Tolerance between readers	Read Aux. to
0.2°C	0.01°C	± 0.03°C	0.1°C
0.1	0.01	0.02	0.1
0.05	0.005	0.01	0.05
0.02	0.001	0.005	0.01
0.01	0.001	0.005	0.01

As with the shallow casts an additional 0.01°C is allowed for each 0.5°C change in the auxiliary.

On deep casts no more than three bottles should be read before rotating readers. This will insure against excessive temperature drift between readings.

E. Malfunctions

1. Types [see Figure 2] - Any thermometer that consistently malfunctions should be replaced by a spare and a new TAS must be made (TAS II, III, IV, etc.) All malfunctions, breakage, and/or losses must also be entered on the Thermometer Malfunction form [see sample Form #3].

In addition to the three common malfunctions described in Figure 2, the following conditions are apt to occur:

(a) More malfunctions will occur on deep casts than on shallow casts. Most thermometers work well at shallow depths but may perform poorly on deep casts.

(b) Occasionally, chips or gouges will appear on thermometer shells. These thermometers should be replaced to avoid implosion on future casts.

(c) Rough winching will often produce a high incidence of "fall through". Thermometers subject to rough treatment will sometimes "fall through" several times then function normally.

2. Correcting malfunctions - Many malfunctions can be corrected by removing the thermometer from the Nansen bottle and reversing it several times. A mercury separation may sometimes be rejoined by gently tapping the instrument against the palm of one's hand, fracturing the stuck mercury into small beads, which can then be rejoined to the main column. When working on thermometers, always be extremely careful.

IV. Processing Deep Sea Reversing Thermometer Data

The *in situ* temperature for any Nansen bottle is determined by averaging the corrected readings of the two protected thermometers. Using this *in situ* temperature and the "temperature" from the unprotected, one can calculate a value which is directly related to the pressure on the thermometer and thus the depth. Multiplication of this value by the "Q factor" (a predetermined factor specific for any unprotected thermometer) gives the depth in meters. This is referred to as the thermometric depth.

Two methods of correcting raw temperatures are used by the Data Collection and Processing Group. These are computer and graphical correction. When graphical corrections are made, only the readings of the senior observer is used. These readings are identified with the subscript "1".

When correcting by graph, care must be taken to use the correct graph. The serial number is printed in the upper left-hand corner and must correspond with the thermometer to be corrected. If there is any doubt, refer to the TAS.

A. Protected thermometers

1. Step 1 - [see sample Form #2 and Figure 3] - Using the plastic scale marked Protected and the graph corresponding to the left protected thermometer determine the correction which is -0.22. Applying this correction to the thermometer reading, we get the corrected temperature, 7.78°C which is T_w left:

$$\begin{array}{r} 8.00 \\ -\ .22 \\ \hline 7.78^\circ C \end{array}$$

2. Step 2 - Using the plastic scale marked Protected and the graph corresponding to the middle protected thermometer determine the correction which is -0.27. Applying this correction to the thermometer reading, we get the corrected temperature, 7.75°C which is T_w middle:

$$\begin{array}{r} 8.02 \\ -\ .27 \\ \hline 7.75^\circ C \end{array}$$

3. Step 3 - After correcting the two protected thermometers, it is necessary to average the two values:

T_w left:	7.78°C
T_w middle:	7.75°
T_w equals:	7.76° (round to the even number)

7.76° is then the final corrected temperature for this Nansen bottle.

B. Unprotected thermometer

1. Step 4 - For the purpose of this calculation only, round off the T_w value to tenths. Then subtract the t_{ul} value from it.

7.76 rounds to 7.8
7.8-17.8 = -10.0 which is $(T_w - t_u)$.

2. Step 4 continued [see Figure 4] - Using the plastic scale marked Unprotected and the graph corresponding to the unprotected thermometer, determine the correction which is -0.30. Applying this correction to the unprotected thermometer reading, we get the corrected value 9.20°C, which is $T_{w,u}$.

$$\begin{array}{r} 9.50 \\ -\underline{\ .30} \\ 9.20°C \end{array}$$

C. Computation of the thermometric depth

1. Step 5 - Subtract the T_w value from $T_{w,u}$ to get 1.44 which is $(T_{w,u}-T_w)$.

2. Multiplication of the $(T_{w,u}-T_w)$ value by 120, the "Q factor" (1/Qrho mean) for the unprotected thermometer gives 173, the depth in meters. 1.44 x 120 = 173 (meters).

D. Preparation for desk computer processing - Most data are processed by computer either at sea or ashore. Many intermediate and short cruises, however, are well suited for processing by small computers (i.e., Olivetti Programma, Calcomp Scientist, WANG, etc.). Before using these programs, certain calibration data must be assembled for each thermometer.

1. Serial number
2. V_o
3. Nansen bottle number and position
4. "Q factor" (unprotected only)
5. Index corrections

Either of two methods are used to compile this information: photocopying of the index curve graphs, or preparing 3 x 5 index cards for each thermometer. Items 1-4 are available from calibration lab records and the TAS. The index corrections must be read from the graph.

To reduce index correction graphs to tabular form, the curves are broken into bands .01°C wide [see Figure 5]. From Figure 5 any reading between 0.0°C and 2.3°C requires an index correction of +.01°C (±.005). From +2.3°C to 4.3°C the index correction is 0.00°C (∓.005), etc. This system is good only to the nearest .01°C, and introduces an additional error no greater than .01°C. If greater accuracy is desired, each correction should be determined from the calibration curve itself.

Nansen bottle No.

56s Left ← Position (in NB)

12-3456 ← DSRT Serial No.

V_o = 100.5 ← V_o

"Q" = 120.0 ← "Q" Factor (unprotected only)

T	Index Corr.
0.0 - 2.3	+.01
2.3 - 4.3	±.00
4.3 - 5.8	-.01
5.8 - 6.0	-.02

TYPICAL (DSRT) INDEX CARD

V. Calibration of Deep Sea Reversing Thermometers

A. Definition of temperature - This department recognizes, and is in the process of converting to, the International Practical Temperature Scale of 1968 as established by the International Committee on Weights and Measures (Comité International, 1969).

The Committee has assigned temperature values to certain freezing points and triple points of various elements and compounds, based on their thermodynamic properties. Some of these reference points are: the triple points of equilibrium of hydrogen, of oxygen, and of water; and the freezing points of tin, zinc, silver, and gold.

The degrees Kelvin and Celsius (formerly Centigrade) are defined by the Comité International (1969) as 1/273.16 of the triple point of water. The triple point of water is set at .01° Celsius and is "exact by definition" (Comité International, 1969).

B. Standard thermometers - Mercury-in-glass stem thermometers are used at this facility to standardize calibration of reversing thermometers. These standards were manufactured to approximate reversing thermometers, as nearly as possible, in bulb size and in glass quality.

The standards consist of two each of the ranges -0.5° to 8°, 8° to 25°, and 25° to 60° Celsius. 0° points are included on all of these instruments. They were manufactured by Richter and Wiese of Berlin in 1954 and have been calibrated by the following laboratories: Physikalish-Technische Bundesanstalt (German "Bureau of Standards"), Naval Electronics Laboratory Center, and U.S. National Bureau of Standards.

Since mid-1967, the standard thermometers have had annual or semi-annual "zero" degree calibration by triple point of water cells.

C. Calibration tank - The thermometer calibration tank was built in 1949 and is made predominately of wood, micarta and lucite, with rack and fittings of stainless steel. Because of the thermal expansion qualities of the micarta, our limits of calibrations are from 0° to 35° Celsius. The walls and lid are 10 cm thick, of which about 7 cm is a styrofoam-like insulation. Inside dimensions are 0.5m x 0.5m x 0.5m, providing a bath capacity of 120 liters.

The bath is stirred by a circular rack which holds twenty-four reversing thermometers. This rack is fitted with eight 10 x 15 cm stirring vanes and is rotated at eleven r.p.m. A pully system allows the rack to be reversed without opening the tank.

D. Viewing system - Thermometer readings are made through a telescope of approximately seven power which is mounted on a vertical traveler. An optical micrometer is incorporated in the eyepiece and allows the average etching interval to be subdivided into about 100 parts. Fractional readings are obtained and converted to temperature values by use of a set of tables.

E. Calibration procedure

1. Index (scale) calibration - The reversing thermometers are checked for proper breaking and for any abnormalities, after which they are loaded into the rack in some logical order (by range and/or serial number). The rack is then locked into place in the tank. One hundred pounds of crushed ice are added and the tank is brought to volume with tap water. The tank and thermometers are allowed to stabilize overnight.

The following morning any ice in excess of about five pounds is removed and the stirring motor is started and engaged. A minimum of one-half hour is allowed for the tank to reach equilibrium.

As the tank stirs, the standard thermometer is carefully monitored to determine when the tank become stable. When the tank has been stable for several minutes, the standard thermometer is read and recorded by each of two readers and the rack is immediately reversed. The reversing thermometers are then read to the nearest one-thousandth degree by each reader [see sample Form #4]. The tolerance between readers is .001°C to .003°C, depending on etching interval.

The process is executed at least twice at each desired temperature level. Usually ten or eleven levels are calibrated on new reversing thermometers, general practice being to bracket the temperature level by about one-twentieth degree.

Upon completion of a temperature level, the tank is adjusted upward to the next desired temperature by adding warm water. The reading process is then repeated until the highest level has been completed.

The readings of both readers for each thermometer at each level are averaged. The mean corrections are calculated and are graphed. The points are fitted with curves which must meet the consensus of two experienced personnel [see Figure 6].

2. Auxiliary thermometer calibration - These calibrations are done in conjunction with main scale calibrations. Readings are made to the nearest 0.01°C and the data are processed similarly to that of the main thermometers.

3. V_o calibration - "V_o" represents the volume of mercury in the bulb and capillary of the main thermometer to the 0.00° etching. The "V_o" is equal to whatever number of degrees of that capillary the volume of mercury would fill. This relationship must be known in order to properly correct for whatever expansion (or contraction) has taken place after the thermometer has been reversed.

The first step in V_o calibration is similar to that of scale calibration. The thermometers are stabilized in an ice bath overnight, then reversed at approximately 0°C. Again two readers read and record the observations of the standard and reversing thermometers.

Next the tank temperature is raised and stabilized, but the thermometers are not reversed. The reading procedure is repeated. General practice at this facility is to calibrate at 0°, 15°, 20°, and 25°C.

At least three methods exist for extracting V_o from the data:

a. By graph (see Figure 7)
b. By computer
c. By the equation: $V_o = \frac{.995K \Delta T}{t}$

Where 1/K = cubical coefficient of expansion of the mercury and glass system together.

t = tank temperature minus tank temperature at "0°".

Δ T = reversing thermometer reading (index corrected) minus the reading at 0°C (index corrected).

The factor ".995" reduces the V_o' by one-half percent, which corrects for the second term of expansion of the logarithmic equation for the expansion of mercury in glass.

VI. "Q" Values for Unprotected DSRT

The Data Collection and Processing Group does not have a pressure tank for determining the "Q" value of unprotected thermometers. The tank at NELC was made available about 2 years ago and the value $\frac{1}{Q \rho m}$ for several unprotected thermometers was determined. These have in turn been used in "Q" casts to check the $\frac{1}{Q \rho m}$ values for other unprotected thermometers. The actual "Q" value is not determined since DCPG uses an average ρm to determine a depth. Depths below 1000 meters are corrected by a table which takes into account the change of density with depth.

A. Instructions for a "Q" cast

1. Select a depth at which to work: DCPG usually uses either 600 or 1000 meters.

2. Make a thermometer arrangement: Intersperse unprotected thermometers having known values of $\frac{1}{Q \rho m}$ with unprotected thermometers of uncertain $\frac{1}{Q \rho m}$ values. Be sure to have known values in the top and bottom bottles [see sample Form #5].

3. Make a cast card for wire lengths of the sample bottles: Place all Nansen bottles 3 meters apart.

4. Lower the cast: Space the Nansen bottles carefully and try to keep the wire angle very small (00° is desired). Watch the terminal reading carefully and take into account any error in meter wheel readings.

B. Processing: Read all thermometers very accurately. Determine the wire lengths and correct all protected and unprotected values to determine $T_{w,u}-T_w$. Calculate thermometric depths for all unprotected thermometers with known values of $\frac{1}{Q \rho m}$

$$\text{Thermometric } Z = (T_{w,u}-T_w) \times \frac{1}{Q \rho m}$$

Plot L vs L-Z for these thermometers and draw the "L-Z curve". [see sample Form #6] Read from this curve values of L-Z for the other unprotected thermometers and get the desired thermometric depth by subtracting this value from the wire length. It should be noted that in this example the L-Z values read off the graph are 0. Therefore, the thermometric depth and the wire length are the same. Now having the thermometric depth and $T_{w,u}-T_w$, a tentative value of $\frac{1}{Q \rho m}$ can be determined.

$$\frac{1}{Q \rho m} = \frac{\text{thermometric } Z}{T_{w,u}-T_w}$$

Several casts should be lowered so an average of several determinations for each unknown unprotected can be made. The thermometer should then be used on succeeding cruises at different depths and in arrangements with other unprotected thermometers to test the determined value.

LITERATURE CITED

Comité International des Poids et Mesures. 1969. International practical temperature scale of 1968. Metrologia 5: 35-44.

TABLE OF FIGURES

TABLE OF SAMPLE FORMS

TABLES OF FIGURES
AND SAMPLE FORMS

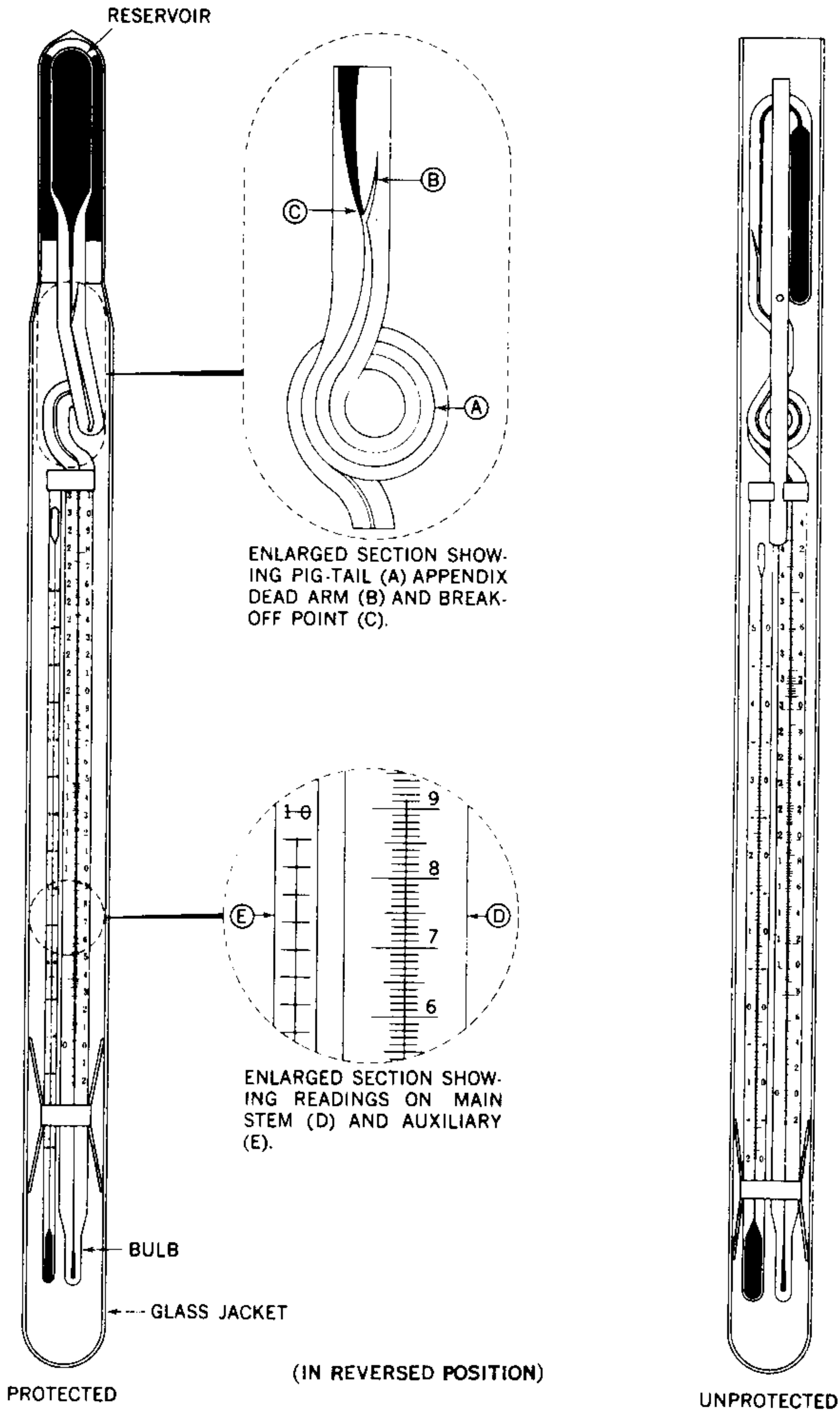


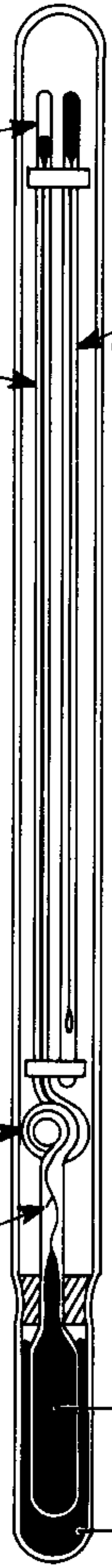
Figure 1 **Protected and unprotected deep-sea reversing thermometers.**

From U. S. Hydrographic Manual, H. O. 607, Reprint 1959

PROTECTED REVERSING THERMOMETER

1. IN SET POSITION (GOING DOWN)

2. IN REVERSED POSITION (COMING UP TO BE READ)



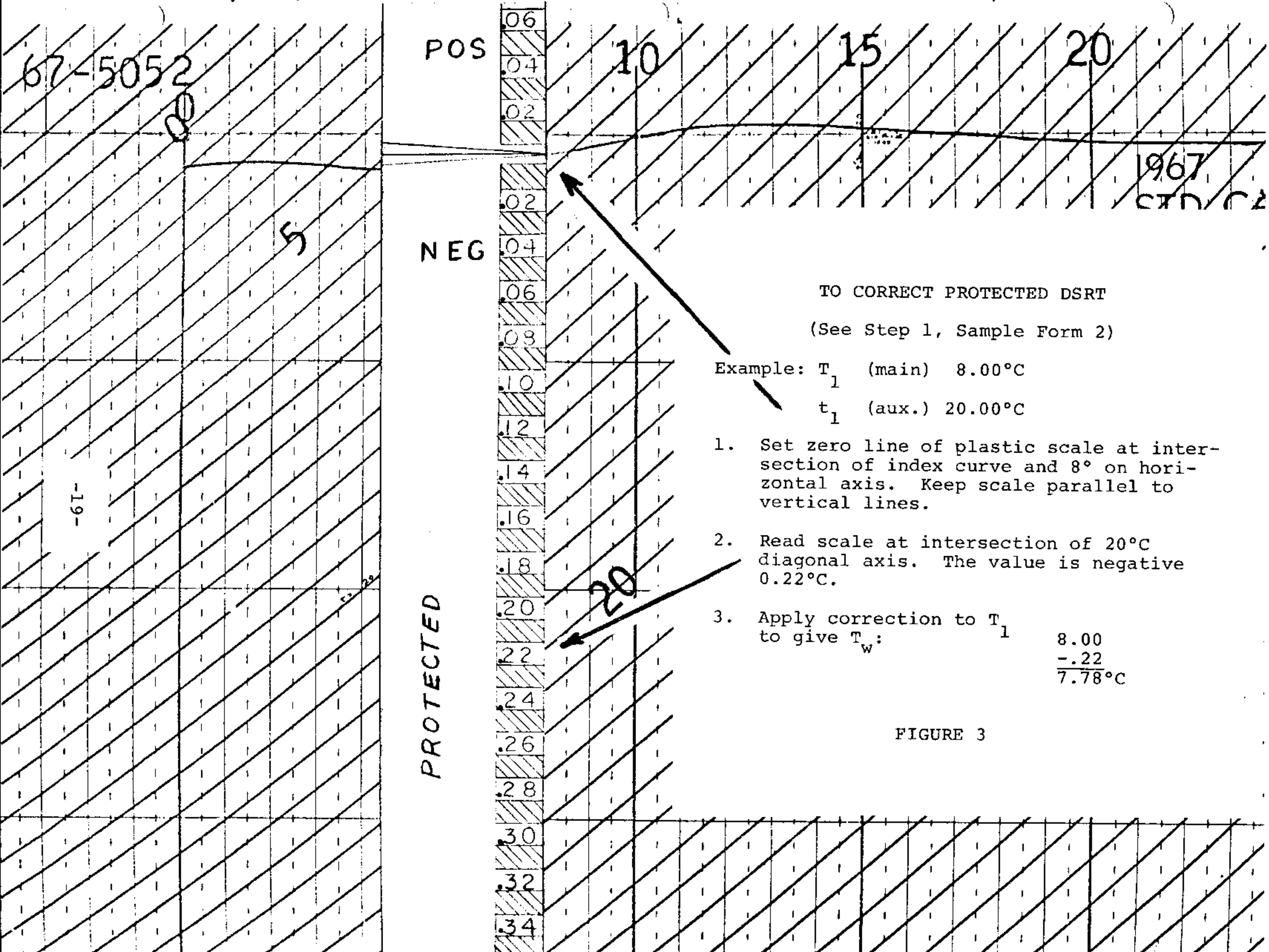
COMMON MALFUNCTIONS

1. FT (FELL THROUGH): When the instrument is reversed, mercury from LARGE RESERVOIR flows down through the constriction at the BREAKING-OFF POINT and completely fills the SMALL BULB and capillary of the MAIN THERMOMETER.

2. WB (WRONG BREAK): When the instrument is reversed, the mercury column of the MAIN THERMOMETER breaks off at some point other than the designated BREAKING-OFF POINT.

3. ST (STUCK): When(the instrument being in set position in preparation for descent) the mercury in the SMALL BULB and upper part of capillary cannot be forced down to connect with the remainder of the mercury system in the LARGE RESERVOIR and lower part of the capillary, there is a "Stuck" malfunction.

FIGURE 2



TO CORRECT PROTECTED DSRT

(See Step 1, Sample Form 2)

Example: T_1 (main) 8.00°C

t_1 (aux.) 20.00°C

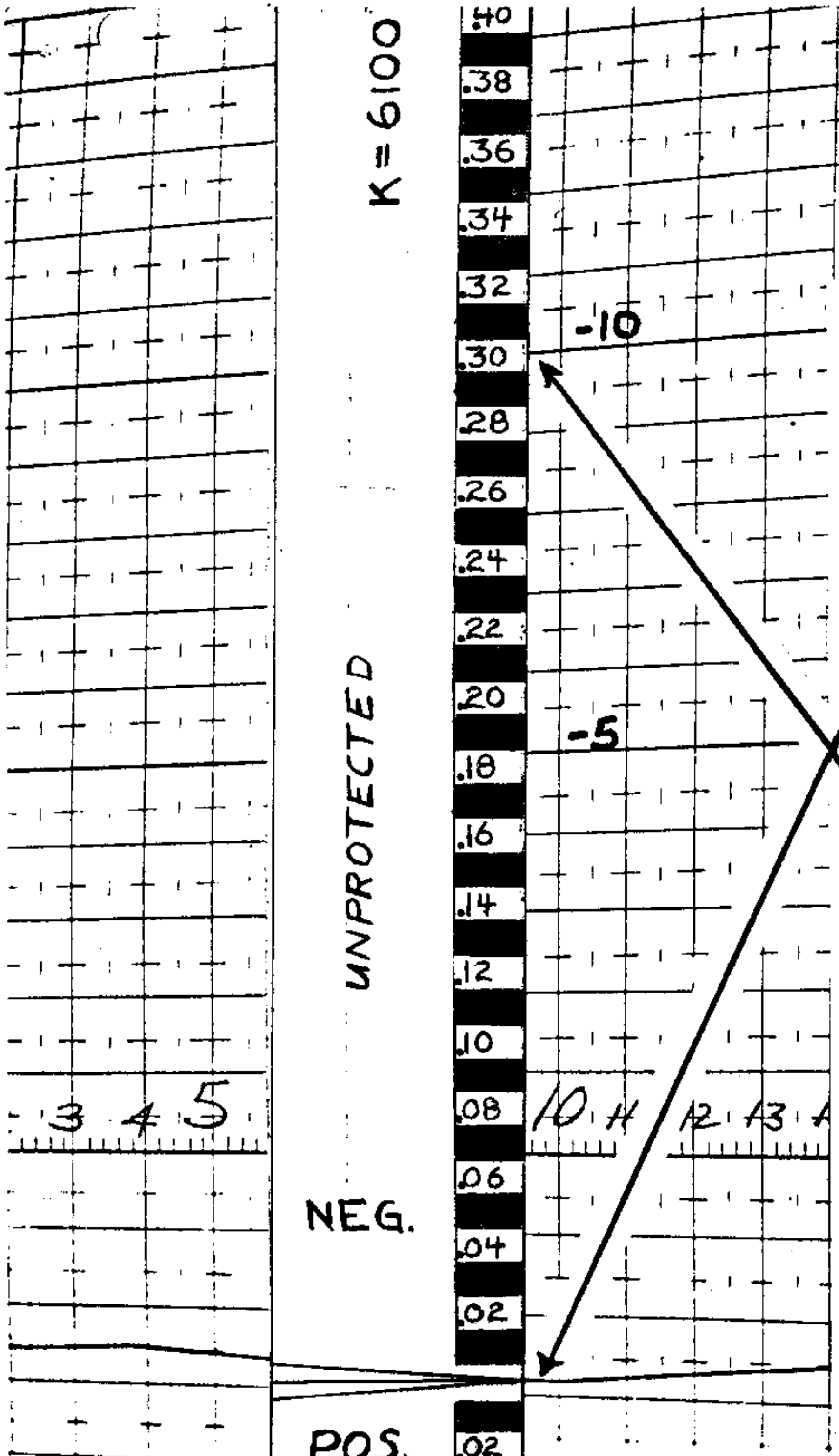
1. Set zero line of plastic scale at intersection of index curve and 8° on horizontal axis. Keep scale parallel to vertical lines.

2. Read scale at intersection of 20°C diagonal axis. The value is negative 0.22°C.

3. Apply correction to T_1 to give T_w:

$$\begin{array}{r} 8.00 \\ \underline{-.22} \\ 7.78°C \end{array}$$

FIGURE 3



TO CORRECT UNPROTECTED DSRT

(See Steps 3 & 4, Sample Form 2)

Example:

T_{ul}	(main)	9.50°C
t_{ul}	(aux.)	17.8 °C
T_w	(average of corrected protected values)	7.76°C
"Q" factor from T.A.S.		120.0

1. Subtract t_{ul} from T_w (-10.0°C).

2. Set zero line of plastic scale at intersection of index curve and 9.50°C (T_{ul}) on horizontal axis. Keep scale parallel to vertical lines.

3. Read scale at intersection of -10.0 (T_w-t_u) on vertical scale. The value is negative 0.30°C.

4. Apply correction to T_{ul} to give $T_{w,u}$:

$$\begin{array}{r} 9.50 \\ \underline{-.30} \\ 9.20°C \end{array}$$

FIGURE 4

SERIAL No. 12-3456
MANUFACTURER
RANGE
K

SYMBOL	CALIB.	DATE	PLOT	Vo	REPAIRS
				100.5	

SIO-MLR-DCPG-1967

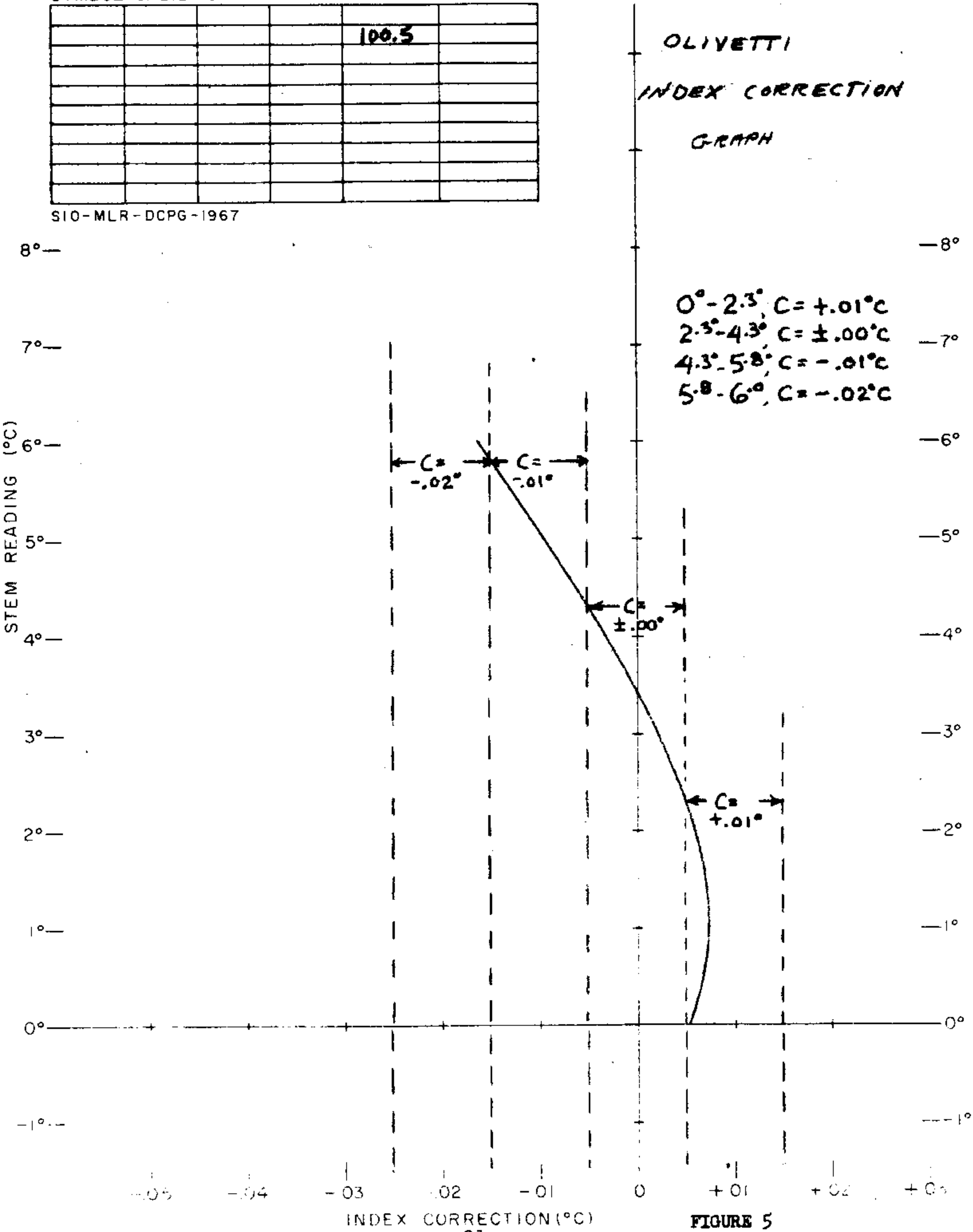


FIGURE 5

SERIAL No. 66-4508
MANUFACTURER KAHL
RANGE -1° to +6°
K 6100

SYMBOL	CALIB.	DATE	PLOT	✓	Vo	REPAIRS
△	SIO	11 Nov'66	[illegible]	[illegible]	105.2	
□	SIO	20 Oct'67	[illegible]	[illegible]		Prior Oct'67

SIO-MLR-DCPG-1967

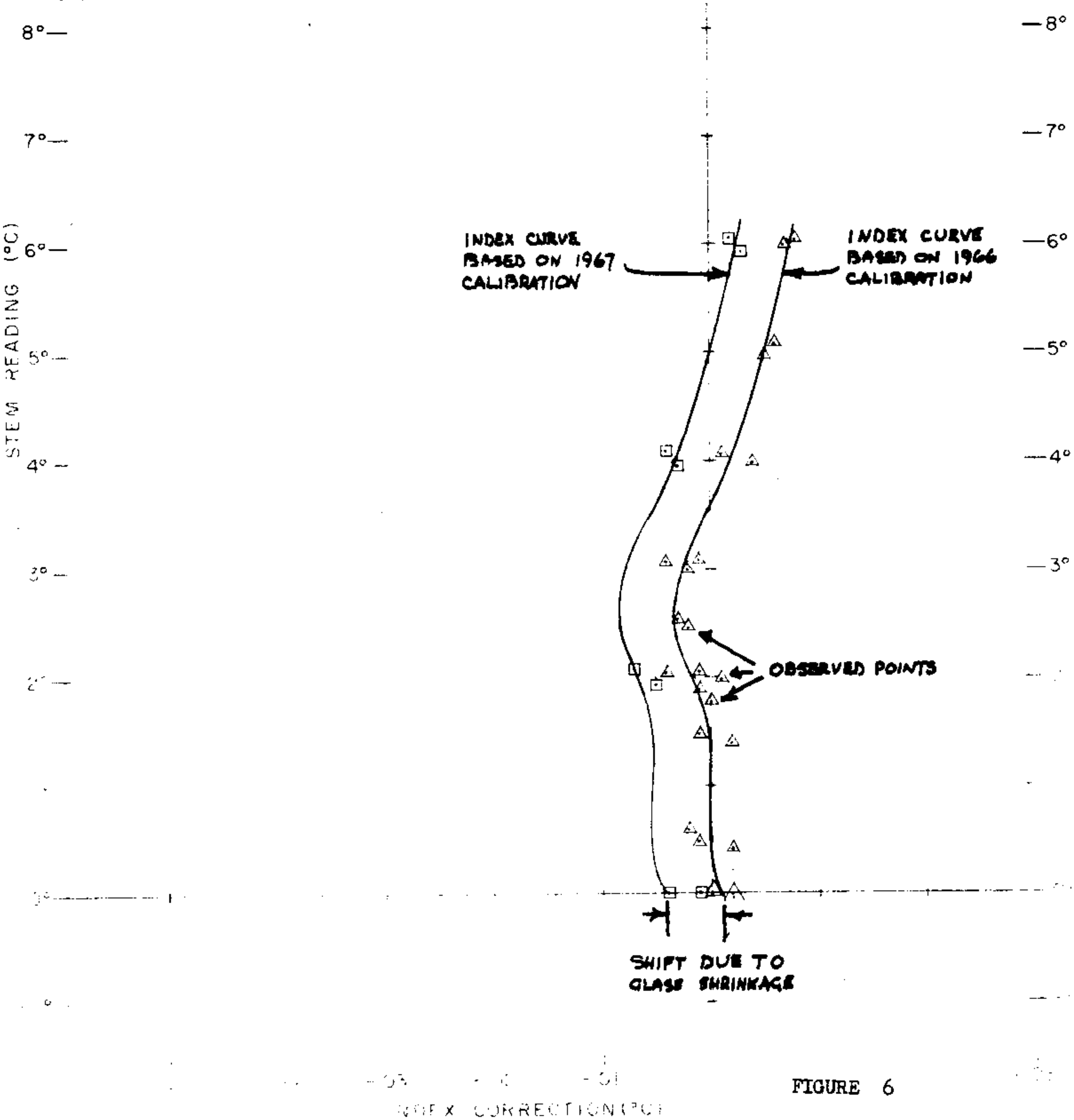
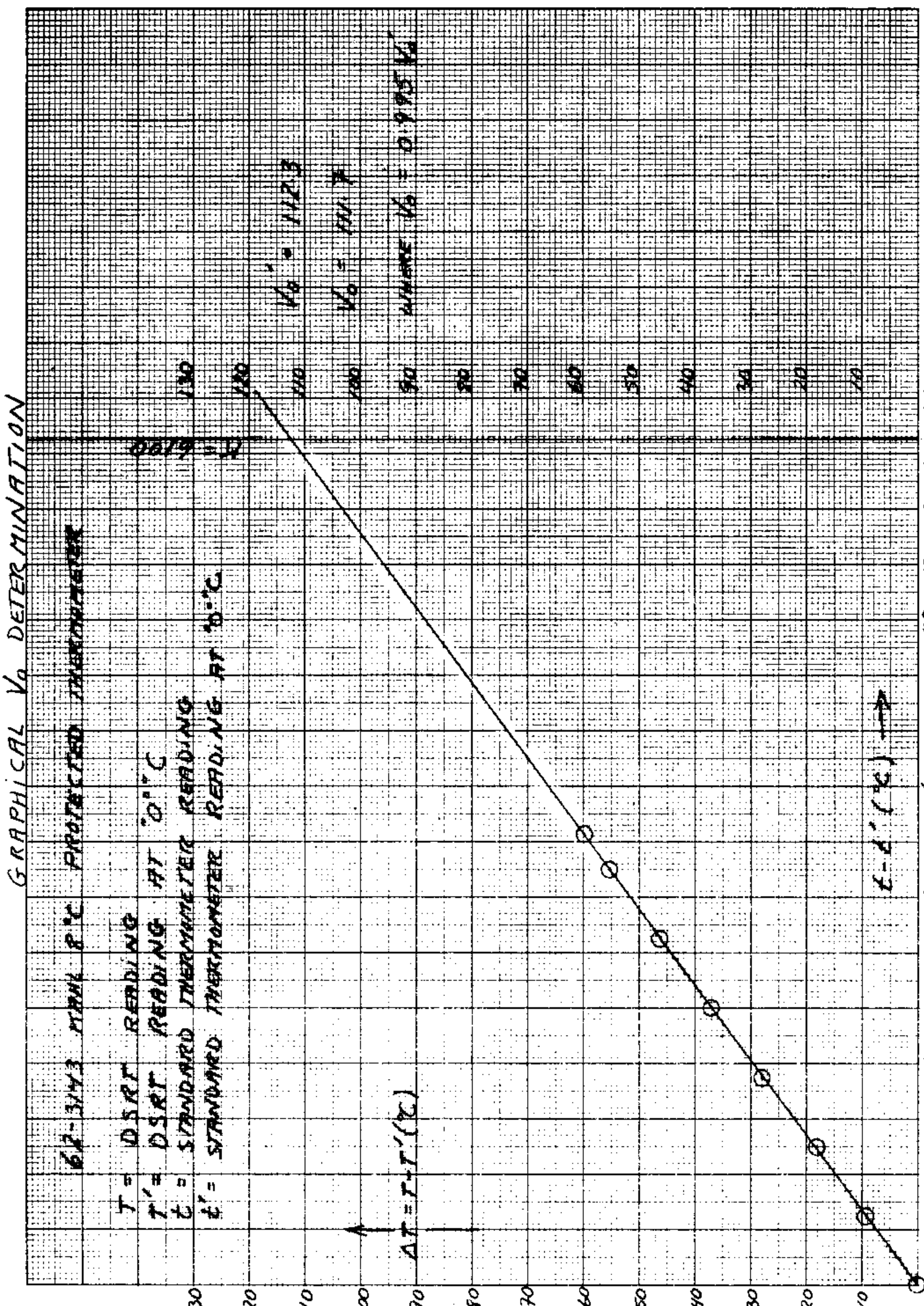


FIGURE 6



GRAPHICAL V_0 DETERMINATION
PROTECTED THERMOMETER
T = DSRT READING
T' = DSRT READING AT 0° C
t = STANDARD THERMOMETER READING
t' = STANDARD THERMOMETER READING AT 0° C
ΔT = T-T' (°C)
t - t' (°C)
V_0' = 112.3
V_0 = 111.7
WHERE V_0 = 0.995 V_0'
1.30
1.20
1.10
1.00
.90
.80
.70
.60
.50
.40
.30
.20
.10
4
8
12
16
20
24
28
32
36
40
44
48
52
56
60
64

FIGURE 7

THERMOMETER ARRANGEMENT

UNIVERSITY OF CALIFORNIA
SCRIPPS INSTITUTION OF OCEANOGRAPHY

ARRANGEMENT BY	THIS TAS SAME AS WB PiQ III TAS III
CHECKED BY	AH
CRUISE	PiQ IV & V
DATE OF FIRST STATION (DAY / MONTH / YEAR)	25 FEB 1969
VESSEL	WASH.
SHEET NO.	I
OF SHEETS	I

STATIONS WORKED WITH THIS ARRANGEMENT
STATION NO. PiQ-IV. #1 THROUGH STATION NO. PiQ-V. #57

REMARKS TO OBSERVERS: ONLY ONE TAS USED

FILL OUT A NEW FORM 1, IN FULL, FOR EACH NEW ARRANGEMENT OF THERMOMETERS. TAS CARD:

METER WHEEL FACTOR	TOTAL N.B.	DATE	TOTAL THERMS. USED
1.02	18	6901	54

SAMPLE FORM 1

REMARKS BY OBSERVERS:

		N. BOT. NO.	NOMINAL DEPTH		PROT. THERMOMETERS	RANGE	UNPROT. THERMOMETERS	RANGE	$\frac{1}{Q_m}$
1	2	6 S		LEFT	5179	30			
				MID.	5180	30			
2	3	5 S		LEFT	56-1494	30			
				MID.	56-1496	30			
3	4	92 S		LEFT	56-1498	30			35°
				MID.	57-1872	30	65-4190		117.8
4	5	93 S		LEFT	58-1957	30			
				MID.	58-1967	30			
5	6	52 S		LEFT	59-2269	30			35°
				MID.	59-2121	30	56-1417		119.6
6	7	17 S		LEFT	56-1493	30			35°
				MID.	59-2124	30	67-5098		131.8
7	8	59 S		LEFT	67-5043	25	BROKEN IN PORT		~~35°~~
				MID.	67-5044	25	~~61-3013~~ NEVER USED		~~121.04~~
8	9	2 S		LEFT	67-5045	25			
				MID.	67-5046	25			
9	10	55 S		LEFT	64-3955	20			35°
				MID.	64-3960	20	65-4186		113.3
10	11	75 S		LEFT	65-4246	16			35°
				MID.	65-4247	16	59-2257		125.13
11	12	90 S		LEFT	66-4887	16			35°
				MID.	65-4249	16	61-2736		116.9
12	13	44 S		LEFT	66-4883	16			35°
				MID.	66-4884	16	67-5095		131.62
13	14	28 S		LEFT	51-0314	15			35°
				MID	49-0589	15	67-5094		132.63
14	15	71 S		LEFT	56-1607	15			35°
				MID.	66-4888	15	67-5096		132.62
15	16	58 S		LEFT	56-1610	15			8-45°
				MID.	56-1577	15	68-5346		125.32
16	17	96 S		LEFT	56-1622	15			8-45°
				MID.	64-3989	15	68-5345		126.82
17	18	45 S		LEFT	55-1284	7			8-45°
				MID.	66-4500	6	68-5352		128.16

	N. BOT. NO.	NOMINAL DEPTH		PROT. THERMOMETERS	RANGE
1	39 S		LEFT	5176	30
			MID.	5177	30

SIO-MLR FORM 1 LA JOLLA, 1950 (MOD. 1957)

ORIGINAL AND PROCESSED OCEANOGRAPHIC DATA

UNIVERSITY OF CALIFOR[NIA]
SCRIPPS INSTITUTION OF OCEANOGRA[PHY]

~~SAMPLE FORM No. 3~~

METER WHEEL	SALINITY	N. BOT.	ACCEPTED DEPTH	PROTECTED THERM. READINGS	CORRECTION	TEMPERATURE

RAW DATA: Protected and Unprotected Readings of the First Reader (T_1 & t_1) Readings of the Second Reader (T_2 & t_2)

LEFT	t_2 20.5	T_2 8.01	T_w	t_{u2} 17.9	T_{u2} 9.50	L
	t_1 20.0	T_1 8.00	C	t_{u1} 17.8	T_{u1} 9.50	Z
MID.	t_2 20.4	T_2 8.02	T_w	T_w	$T_{w,u}$	$T_{w,u}-T_w$
	t_1 20.0	T_1 8.02	C	T_w-t_u	C_u	L-Z

STEP 1
Left Protected Correction

LEFT	t_2	T_2	T_w 7.78	t_{u2}	T_{u2}	L
	t_1 20.0	T_1 8.00	C −.22	t_{u1}	T_{u1}	Z

STEP 2
Middle Protected Correction

MID.	t_2	T_2	T_w 7.75	T_w	$T_{w,u}$	$T_{w,u}-T_w$
	t_1 20.0	T_1 8.02	C −.27	T_w-t_u	C_u	L-Z

STEP 3
Average of Corrected (Protected) Values

LEFT	t_2	T_2	T_w 7.78	t_{u2}	T_{u2}	L
	t_1	T_1	C	t_{u1}	T_{u1}	Z
MID.	t_2	T_2	T_w 7.75	T_w 7.76	$T_{w,u}$	$T_{w,u}-T_w$
	t_1	T_1	C	T_w-t_u	C_u	L-Z

STEP 4
Unprotected Correction

LEFT	t_2	T_2	T_w	t_{u2}	T_{u2}	L
	t_1	T_1	C	t_{u1} 17.8	T_{u1} 9.50	Z
MID.	t_2	T_2	T_w	T_w 7.76	$T_{w,u}$ 9.20	$T_{w,u}-T_w$
	t_1	T_1	C	T_w-t_u −10.0	C_u −.30	L-Z

STEP 5
Calculation of $T_{w,u}-T_w$ & Thermometric Depth

LEFT	t_2	T_2	T_w	t_{u2}	T_{u2}	L
	t_1	T_1	C	t_{u1}	T_{u1}	Z 173
MID.	t_2	T_2	T_w	T_w 7.76	$T_{w,u}$ 9.20	$T_{w,u}-T_w$ 1.44
	t_1	T_1	C	T_w-t_u	C_u	L-Z

STEPS 1-5
Combined

LEFT	t_2 20.5	T_2 8.01	T_w 7.78	t_{u2} 17.9	T_{u2} 9.50	L
	t_1 20.0	T_1 8.00	C −.22	t_{u1} 17.8	T_{u1} 9.50	Z 173
MID.	t_2 20.4	T_2 8.02	T_w 7.75	T_w 7.76	$T_{w,u}$ 9.20	$T_{w,u}-T_w$ 1.44
	t_1 20.0	T_1 8.02	C −.27	T_w-t_u −10.0	C_u −.30	L-Z

THERMOMETRIC DEPTH COMPUTATIONS

CRUISE | STATION | DATE 19 | ACCEPTED POSITION °N | VESSEL | TIME | OBSERVER NO. 1 | OBSERVER NO. 2 | WIRE ANGLE | ASSISTANT | START DOWN | ARRIVE DOWN | MESSENGER | CHLORINITY BOX NO. | START UP | THERMOMETER ARRANGEMENT NO.

REMARKS

ROUTINE

SAMPLE FORM 2

Q FACTOR

1.44 × 120 = 172.[8]

SEE S.I.O. REPORT: *MODIFI[ED] FORMS AND PROCEDURES FOR PROCESSING PHYSIC[AL] OCEANOGRAPHIC DATA*
R.O. REID AND H.T. KLEIN

SIO-MLR FORM
LA JOLLA, 1950 (MOD. 195[?])

THERMOMETER MALFUNCTION, LOSS AND BREAKAGE

UNIVERSITY OF CALIFORNIA
SCRIPPS INSTITUTION OF OCEANOGRAPHY

LEGS IV & V

OBSERVER IN CHARGE	MONTH(S) / YEAR	VESSEL	SHEET NO.	OF SHEETS	CRUISE
HESTER - PALMER	FEB MAR. APRIL 1969	T. WASHINGTON			PIQUERO

CHECK WHICH: REVERSING P	CHECK WHICH: REVERSING U	CHECK WHICH: SURFACE	SERIAL NUMBER	CHECK WHICH: MALFUNCTION	CHECK WHICH: LOSS OR DAMAGE	IF MALFUNCTION, INCLUDE TALLY: WRONG BREAK	FELL THROUGH	STUCK	DETAILS: IF LOSS OR BREAKAGE, INCLUDE STATION NUMBER WHERE MISHAP OCCURRED	REPAIRS EFFECTED AT SEA	TO BE FILLED OUT AFTER CRUISE BY SHORE LABORATORY PERSONNEL: CONDITION ON RETURN (BY ___)	DISPOSITION (BY ___)	FILE
✓			5 LEFT 56-1494	✓		~~IIII~~ III			(5 MIDDLE) CHECK ALSO 56-1496				
✓			28 MIDDLE 49-0589	✓		II		~~IIII~~ I					
✓			55 MIDDLE 64-3960	✓			III						
✓			45 MIDDLE 66-4500	✓			I						
✓			2 67-5045 67-5046	✓		????? ✓			SOMETIMES BEYOND AVERAGING LIMITS OF 0.5-0.8°C [POSS. ERROR IN PROGRAM] CHECK				
	✓		96 UNPRO 68-5345	✓		I							
	✓		45 UNPRO 68-5352	✓				I					
	✓		59 UNPRO 61-3013		✓				BETWEEN LEGS III & IV BROKEN WHILE IN PORT; VALPO.				
									SAMPLE FORM 3				

THERMOMETER CALIBRATIONS

UNIVERSITY OF CALIFORNIA
SCRIPPS INSTITUTION OF OCEANOGRAPHY

THIS RACK WAS FILLED TO NO.	BATCH NO.	OF BATCHES	DESIRED TEMPERATURE	HIGHEST DESIRED TEMPERATURE IN THIS BATCH	READER NO. 1 / READER NO. 2	COMPUTER / CHECKER	CHECK WHEN PLOTTED	CALIBRATION DATE
24			0, 2, 4, 6 °C	6°C	BRYAN / MAY	→ / →		20 OCTOBER 1967 (DAY MONTH YEAR)

STANDARD 5661

RANGE, TYPE →

	STARTING TIME OF	RACK NO. / THERMO. NUMBER	1 / 13	2 / 14	3 / 15	4 / 16	5 / 17	6 / 18	7 / 19	8 / 20	9 / 21	10 / 22	11 / 23	12 / 24
		THERMO. NUMBER		5661 ←	SERIAL NO. OF STANDARD THERMOMETER					66-4503	SERIAL NO. OF DEEP SEA REVERSING THERMOMETER			
FIRST REVERSAL	STIR	READER 1		0.026 ←	STANDARD READING, 1ST READER					0.000 ←	D.S.R.T. READING, 1ST READER			
		READER 2		0.026 ←	" " 2nd READER					0.000 ←	D.S.R.T. " 2nd READER			
		Av.		0.026 ←	AVERAGE OF 1ST & 2nd READERS					0.000 ←	AVERAGE OF 1ST & 2nd READERS			
	REVERSE	T_w		-0.004 ←	CORRECTED WATER TEMPERATURE									
	0945	I		-0.030 ←	INDEX CORRECTION					-0.004 ←	CORRECTION REQUIRED			
SECOND	STIR	READER 1		0.032						0.003				
		READER 2		0.032						0.003				
		Av.		0.032	SAME AS ABOVE					0.003	SAME AS ABOVE			
	REVERSE	T_w		+0.002										
	1100	I		-0.030						-0.001				
THIRD	STIR	READER 1		1.967						1.943				
		READER 2		1.967						1.942				
		Av.		1.967	SAME AS ABOVE					1.942	SAME AS ABOVE			
	REVERSE	T_w		1.937										
	1305	I		-0.030						-0.005				
REMARKS OR FOURTH	STIR	READER 1		2.083						2.060				
		READER 2		2.083						2.059				
		Av.		2.083	SAME AS ABOVE					2.060	SAME AS ABOVE			
	REVERSE	T_w		2.053										
	1345	I		-0.030						-0.007				
SUMMARY	RANGE OF "GOOD" Av. READINGS													
	ACCEPTED READING													
	✓													
	ACCEPTED CORRECTION													
	RANGE OF CORRECTIONS													

SAMPLE FORM 4

THERMOMETER ARRANGEMENT

UNIVERSITY OF CALIFORNIA
SCRIPPS INSTITUTION OF OCEANOGRAPHY

ARRANGEMENT BY	CHECKED BY	CRUISE
F. WILKES		

DATE OF FIRST STATION (DAY / MONTH / YEAR)	VESSEL	SHEET NO.	OF SHEETS
MAY 19 70	HORIZON	1	

STATIONS WORKED WITH THIS ARRANGEMENT

STATION NO. Q1. THROUGH STATION NO. Q6.

REMARKS TO OBSERVERS:

FILL OUT A NEW FORM I, IN FULL, FOR EACH NEW ARRANGEMENT OF THERMOMETERS.

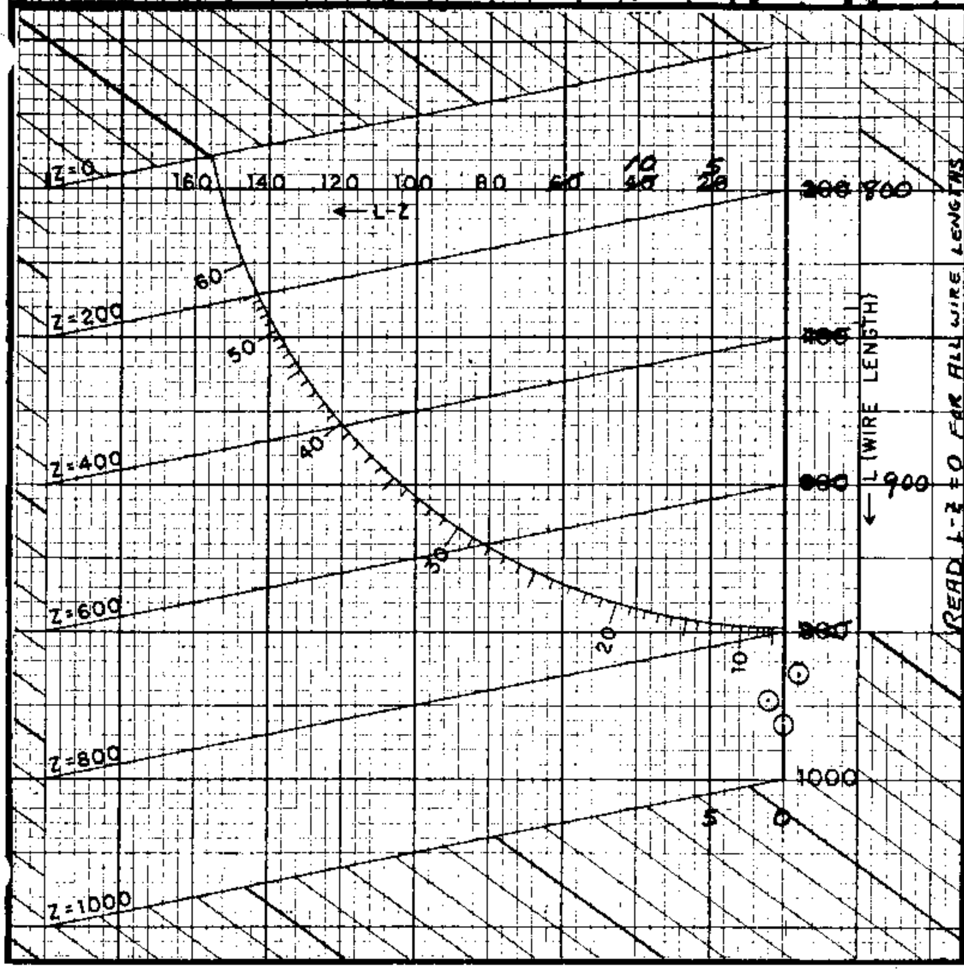
SAMPLE FORM 5

	N. BOT. NO.	NOMINAL DEPTH		PROT. THERMOMETERS	RANGE	UNPROT. THERMOMETERS	RANGE	1/Q0	REMARKS BY OBSERVERS
1			LEFT						
			MID.						
2			LEFT						
			MID.						
3			LEFT						
			MID.						
4			LEFT						
			MID.						
5			LEFT						
			MID.						
6			LEFT						
			MID.						
7			LEFT						
			MID.						
8			LEFT						
			MID.						
9			LEFT						
			MID.						
10	30		LEFT	5203	16		35°		
			MID.	62-33111	16	61-27388		114.5	
11	25		LEFT	65-42477	16		35°		CALCULATED FROM Q CAST
			MID.			67-50955		UNKNOWN	132.6
12	3		LEFT	65-42488	16		35°		
			MID.			59-22577		UNKNOWN	132.7
13	44		LEFT	66-48844	16		35°		
			MID.			61-30133		121.1	
14	11		LEFT	66-48877	16		35°		
			MID.	68-53100	16	67-50977		UNKNOWN	133.0
15	39		LEFT	68-53111	16		35°		
			MID.			68-53466		UNKNOWN	126.8
16	61		LEFT	51-03144	15		35°		
			MID.			55-13066		118.6	
17			LEFT						
			MID.						

	N. BOT. NO.	NOMINAL DEPTH		PROT. THERMOMETERS	RANGE
			LEFT		
			MID.		

SIO-MLR FORM I LA JOLLA, 1950 (MOD. 1957)

METER WHEEL	SALINITY	N. BOT.	ACCEPTED DEPTH	PROTECTED THERM. READINGS	CORRECTION	TEMPERATURE	THERMOMETRIC DEPTH COMPUTATIONS



SIO MLR DCPG FORM 29

Line	UP	DN	DIF	Meter wheel	N. Bot. No.	Accepted L	Left t	Left T	Left C	Left T_w	Mid t	Mid T	Mid C	Mid T_w	t_u	T_w	$T_w - t_u$	T_u	$T_{w,u}$	C_u	L	Z	$T_{w,u} - T_w$	L−Z
11	61	61	0	964	30	964	22.3 / 21.7	4.19 / 4.17	−.36	3.81	22.2 / 21.8	4.15 / 4.14	−.34	3.80	21.8 / 21.2	3.80	−17.4	12.70 / 12.67	12.23	−.44	964	965	8.43	−1
12	58	58	0	967	25	967	22.1 / 21.8	4.13 / 4.12	−.32	3.80					21.8 / 21.3	3.80	−17.5	11.58 / 11.56	11.09	−.47	967		7.29	
13	55	55	0	970	3	970	22.3 / 22.0	4.13 / 4.12	−.33	3.79					22.1 / 21.7	3.79	−17.9	11.57 / 11.55	11.10	−.45	970		7.31	
14	52	52	0	973	44	973	22.5 / 22.0	4.13 / 4.12	−.34	3.78					22.3 / 22.0	3.78	−18.2	12.27 / 12.26	11.81	−.45	973	972	8.03	1
15	49	49	0	976	11	976	22.4 / 22.1	4.11 / 4.10	−.33	3.77	22.2 / 21.9	4.09 / 4.08	−.31	3.77	22.1 / 21.9	3.77	−18.1	11.58 / 11.57	11.11	−.46	976		7.34	
16	46	46	0	979	39	979	22.2 / 21.8	4.10 / 4.08	−.32	3.76					22.0 / 21.7	3.76	−17.9	11.94 / 11.92	11.48	−.44	979		7.72	
17	43	43	0	982	61	982	22.3 / 21.7	4.11 / 4.10	−.35	3.75					22.4 / 22.0	3.75	−18.2	12.44 / 12.44	12.03	−.41	982	982	8.28	0
18																								

ORIGINAL DATA

DATE 18 MAY 1970 (DAY, MONTH, YEAR)

CRUISE

STATION: Q CAST

VESSEL: HORIZON

ACCEPTED POSITION: 28° 33.' N 138° 14.' W (LATITUDE, LONGITUDE)

WIND: DIR. FORCE — CLOUDS: TYPE AMT.

BAROMETER — SWELL: DIR. HT. FT. PERIOD S

WEATHER — WET BULB °F — DRY BULB °F

CAST: 1025 Q — OBSERVER NO. 1 — OBSERVER NO. 2

WIRE ANGLE: 00° — ASSISTANT

START DOWN: 2010 — BT. INSTR. NO. — BT. SLIDE NO.

ARRIVE DOWN — DEPTH FATH.

SAMPLE FORM 6

MESSENGER: 2023 — CALCULATION NO.

START UP: 2033 — THERMOMETER ARRANGEMENT NO.

IN: 2045 — TERMINAL READING 1030

REMARKS

967 ÷ 7.29 = 132.6

L-Z READ FROM CURVE

970 ÷ 7.31 = 132.7

L-Z READ FROM CURVE

976 ÷ 7.34 = 133.0

L-Z READ FROM CURVE

979 ÷ 7.72 = 126.8

L-Z READ FROM CURVE

SEE S.I.O. REPORT: *MODIFIED FORMS AND PROCEDURES FOR PROCESSING PHYSICAL OCEANOGRAPHIC DATA* BY R.O. REID AND H.T. KLEIN

SIO-MLR-DCPG FORM 2.52 LA JOLLA, 1965 (MOD. 1965)