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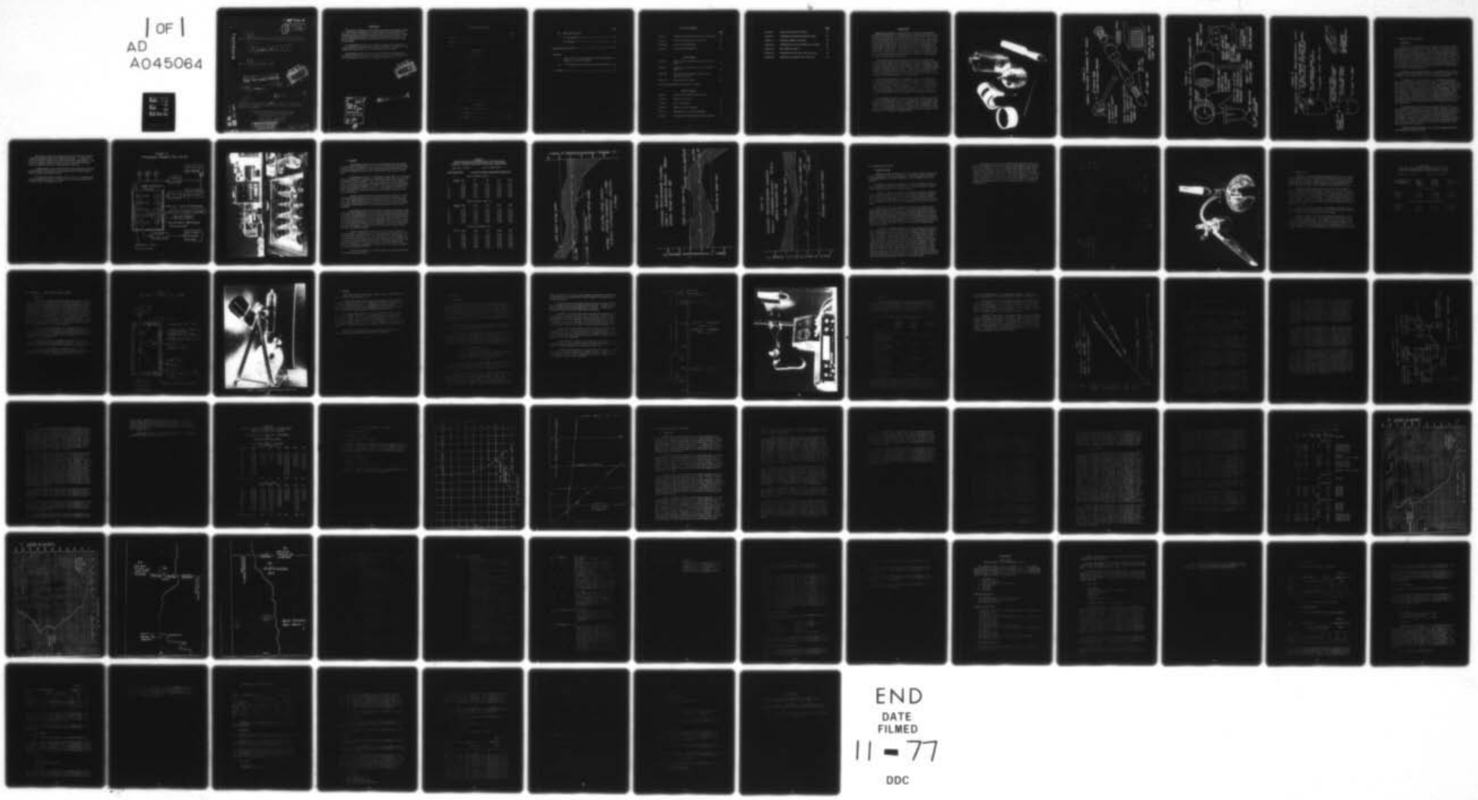

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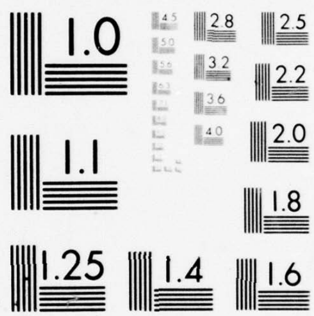

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

MOST Project -2

INFORMAL MANUSCRIPT REPORT. NO. I-1-64

TITLE: EXPENDABLE BATHYTHERMOGRAPH EVALUATION.

NOO-IM-I-1-64

AUTHOR: WALTER L. REID, JR

76p.

DATE: DECEMBER 1964

This manuscript has a limited distribution, therefore in citing it in a bibliography, the reference should be followed by the phrase UNPUBLISHED MANUSCRIPT.

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ABSTRACT

Expendable bathythermographs (BTs) submitted by General Motors, Inc. and Francis Associates, Inc. were tested to determine the temperature indication accuracies attainable from their thermistor-bridge temperature sensing circuits and the depth accuracy obtainable from their procedure of utilizing a known BT sink rate to determine instantaneous depth.

An expendable BT unit with a platinum temperature sensor and a built in pressure transducer was submitted by Basic Devices, Inc., but malfunctions within the unit limited the extent of evaluation.

Laboratory and field testing provided information sufficient for an evaluation of the technical feasibility of the expendable BT concepts and also provided some indication of operational capabilities.

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FOREWORD

Expendable bathythermographs thus far evaluated by this Office were preproduction units submitted by the Packard Electric Division of General Motors Corporation and Francis Associates, Inc. These BTs are essentially similar in concept, consisting of compact, streamlined instrument vehicles designed to sink at a constant rate while paying out a fine electrical cable from a bail located within the instrument body. A thermistor located at the nose of the instrument senses the ocean temperature and regulates a corresponding d. c. signal which is transmitted back to recording instruments aboard ship via the deployed electrical cable. Wire is also payed out from a second coil on board the ship to allow the wire to remain essentially stationary in the water as the ship progresses along its course.

Temperature signal readout instrumentation consists of a strip chart recorder located on board the ship. Since the velocity of the sensor vehicle through the water is essentially constant, a relationship between depth and time is established and thus the time axis of the recorder chart is directly related to depth. A large scale temperature-depth profile from the water surface down to 1500 feet is produced in less than two minutes from the time of BT launching while the ship remains on course and maintains speeds up to twenty knots.

A prototype expendable BT incorporating a pressure transducer and having all electrical cable deployed from the ship was developed and submitted by Basic Devices, Inc., but problems within the temperature sensing circuit necessitated returning the units to the manufacturer for modification. The modified units were not returned in time for laboratory analysis; field testing provided insufficient data for evaluation of the Basic Device expendable BT's operating characteristics.

The expendable bathythermograph evaluation conducted by this Office was concerned primarily with an engineering concept, rather than an operational production device. Laboratory testing included studies of temperature accuracy, thermal response time, the effects of pressure upon the temperature sensors, and uniformity of sink rate. Field testing of the expendable bathythermographs was performed to provide information on operational characteristics.

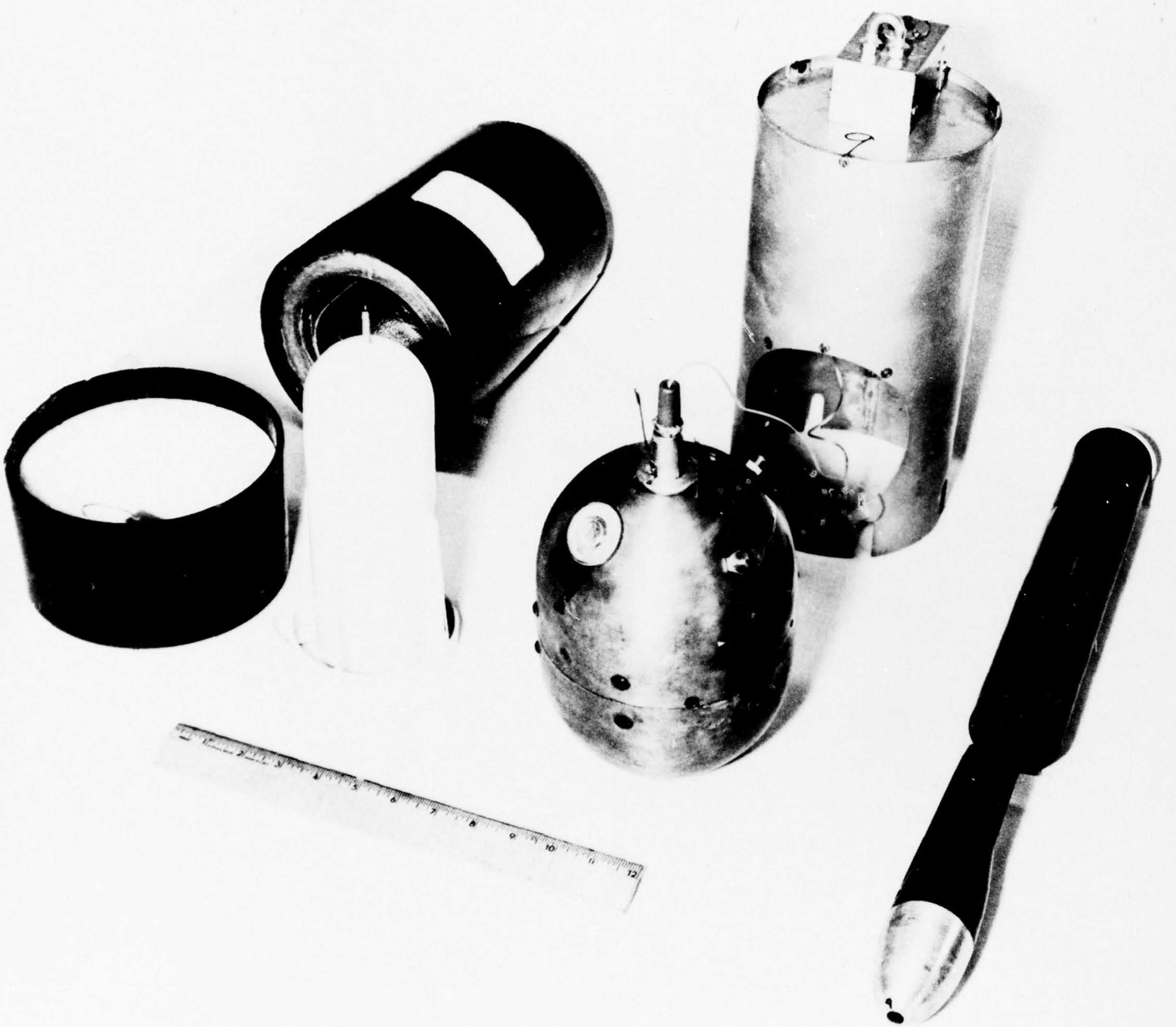


FIGURE 1 - EXPENDABLE BT UNITS, LEFT TO RIGHT - GENERAL MOTORS, BASIC DEVICES, FRANCIS ASSOCIATES

FIGURE 2.
FRANCIS ASSOCIATES EXPENDABLE BT SYSTEM

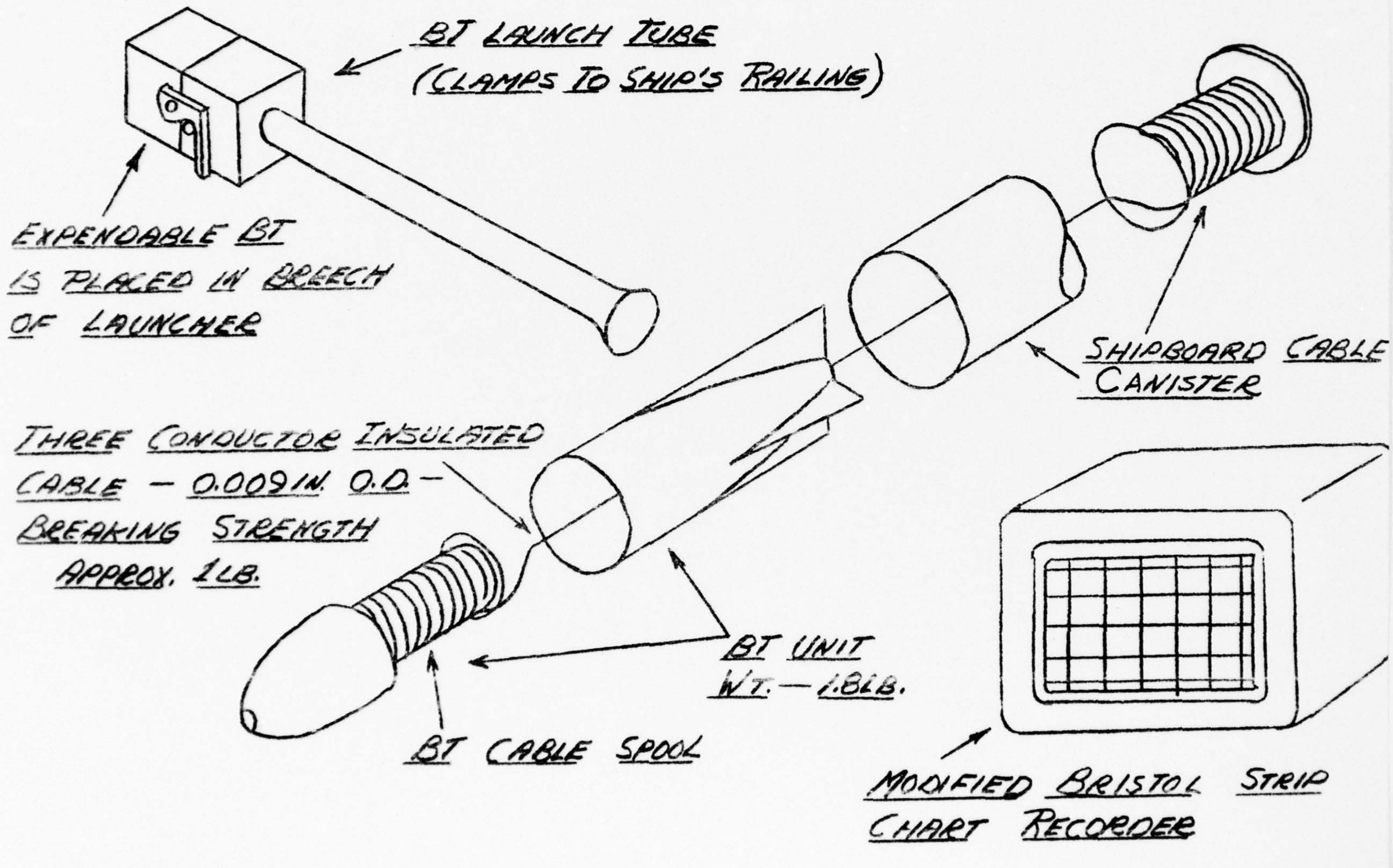


FIGURE 3.

GENERAL MOTORS TYPES 'A' AND 'B' EXPENDABLE BTs

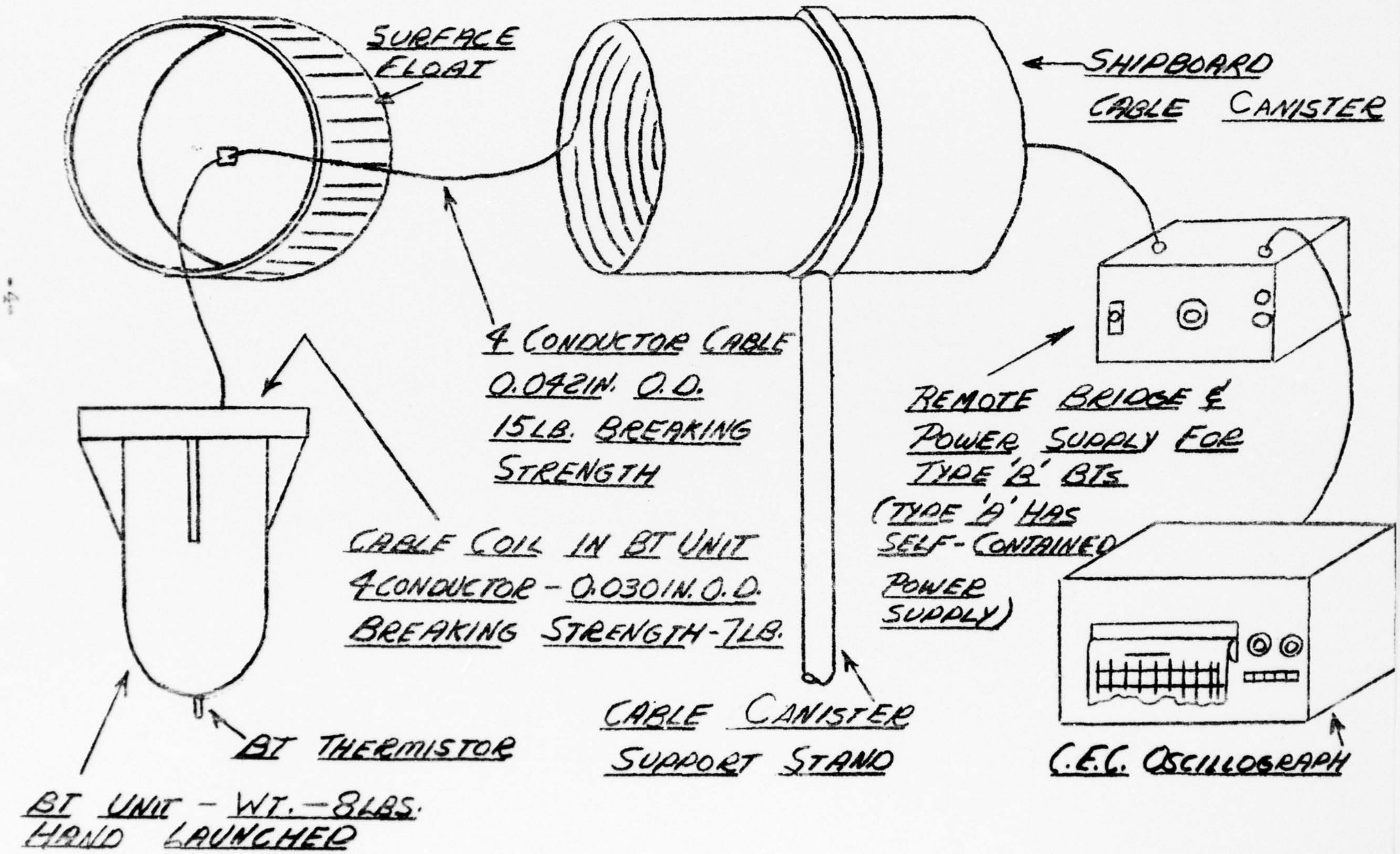
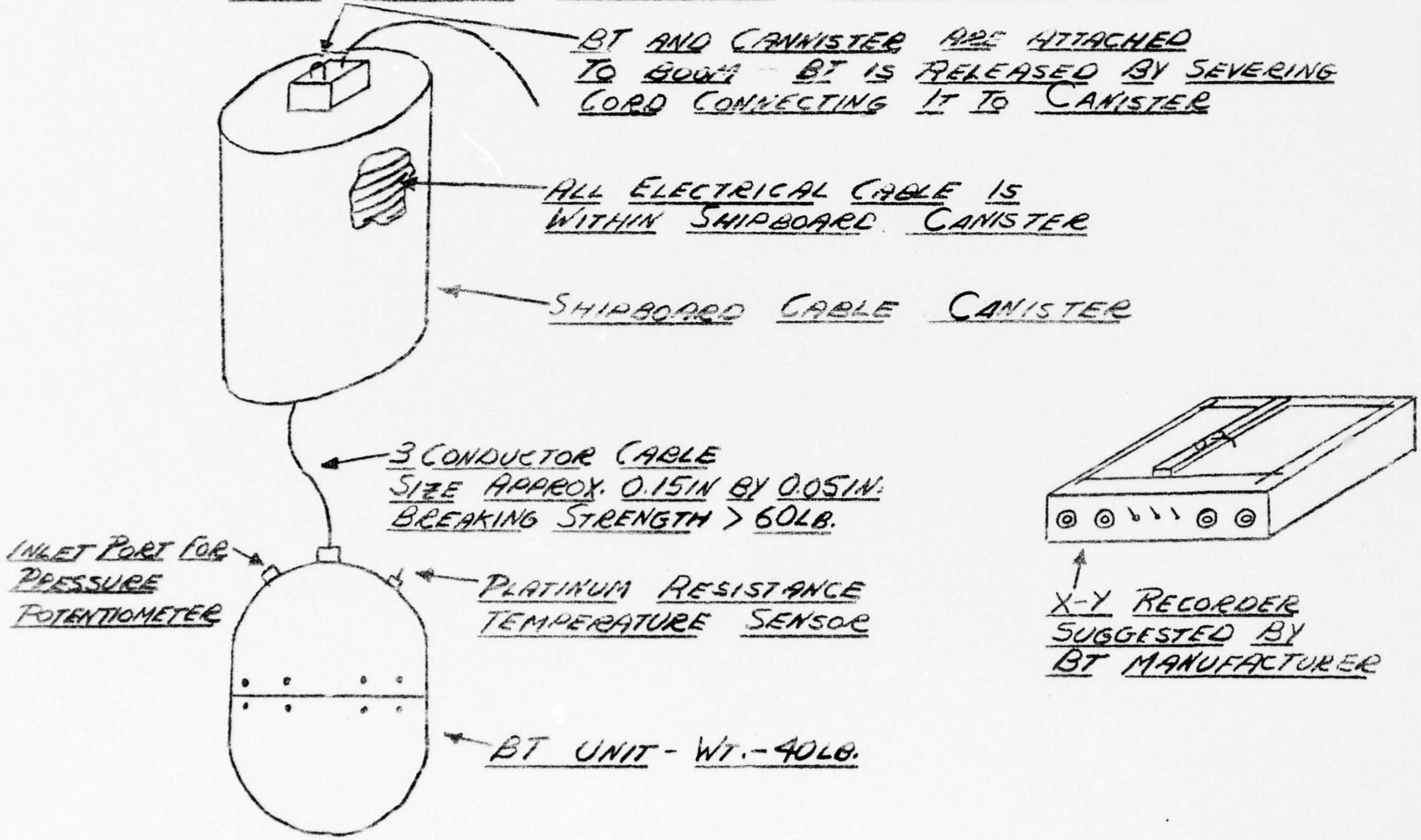


FIGURE 4.

BASIC DEVICES EXPENDABLE BATHYTHERMOGRAPH SYSTEM



I. TEMPERATURE ACCURACY

A. Procedure

Five units of each BT type were utilized for laboratory evaluation of the expendable bathythermograph concept. The units originally submitted by Basic Devices, Inc., failed to function properly and were returned to the manufacturer for modification of the temperature sensing circuit; however, the modified units were not returned in sufficient time for laboratory evaluation prior to the issuance of this report. The remaining BT units, five each of the General Motors types "A" and "B" units and five of the Francis Associates units, were subjected to testing of their temperature sensors and associated circuitry to determine if the $\pm 0.20^{\circ}C$ temperature accuracy desired by the U. S. Naval Oceanographic Office had been achieved.

Recording instruments supplied with the expendable BTs were replaced with precision digital-readout instruments to provide a better indication of actual BT errors and to facilitate data collection.

The fifteen BT units were placed in a regulated temperature bath and completely submerged with tap water. A supporting rack was fabricated of hardware cloth to provide free circulation around the units and to separate them from the tank corners, cooling coils, heating elements, and any other region where non-uniform temperature conditions might have increased the apparent errors of the BT readings. Bath temperatures were determined by use of a thermistor thermometer (H. R. B. Singer). The thermometer, calibrated before and after the temperature tests, was accurate and repeatable to $\pm 0.02^{\circ}C$. Two mercury-glass thermometers, calibrated and readable to $\pm 0.025^{\circ}C$, were included in the bath to provide information on uniformity of temperature distribution.

Bath temperatures and BT readings were taken at $5^{\circ}C$ increments over the BT operating range of 0 to $30^{\circ}C$, with this cycle repeated three times for increasing and three times for decreasing temperatures to give sufficient data on BT temperature sensing accuracy and uniformity between units. The bath was allowed to stabilize for at least fifteen minutes at each temperature test point before any readings were taken. The bath temperature was continuously monitored as BT readings were taken to insure that all BT readings were taken under stable temperature conditions.

Three-five position switch boxes were fabricated to facilitate rapid selection of BTs for testing.

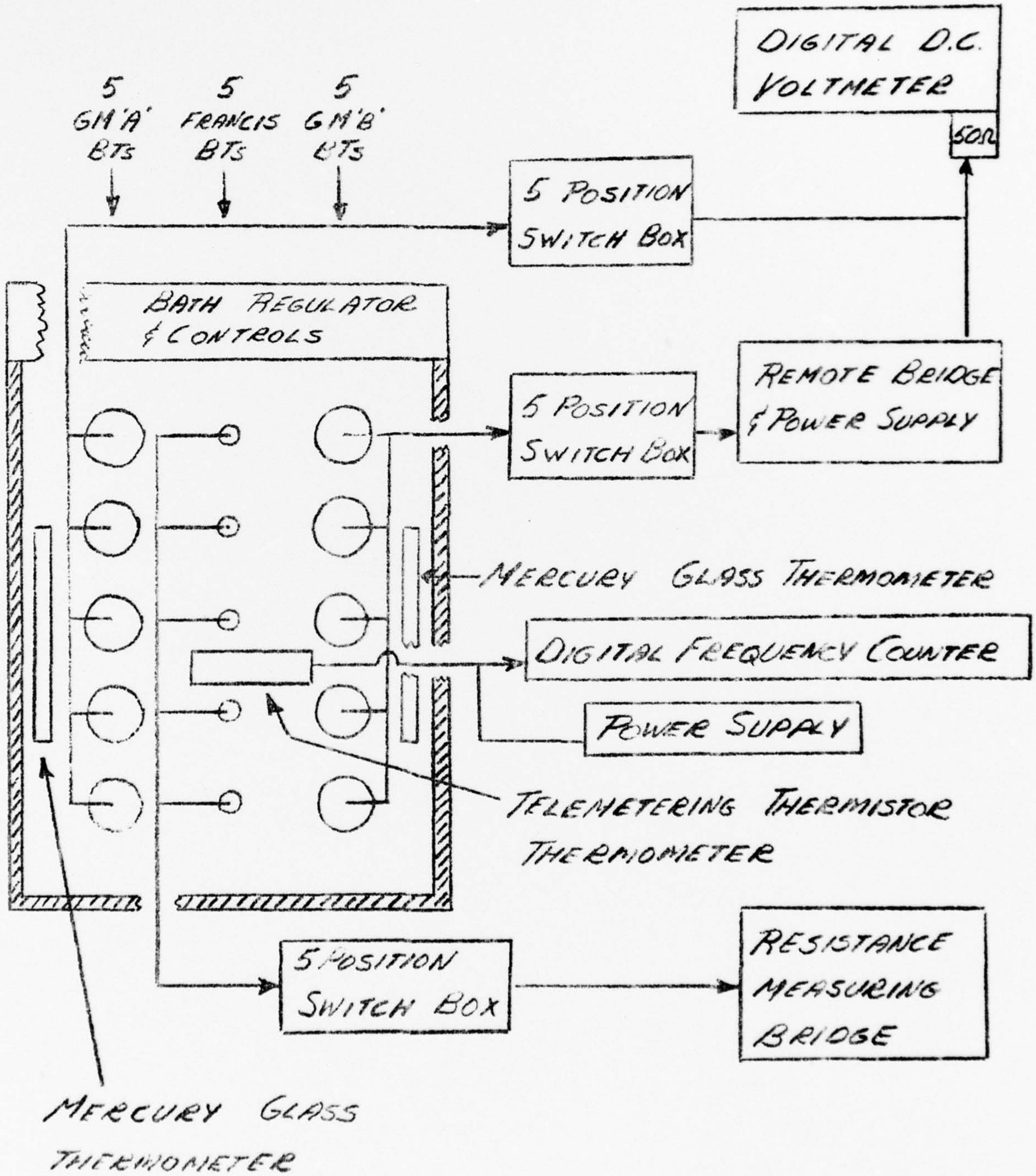
The current output of the General Motors BT units was read as a voltage drop across a precision fifty ohm resistor. A digital voltmeter was utilized in determining the resultant BT voltage output. The meter was checked before each test run with its internal calibration points and checked daily with a laboratory standard cell.

A direct digital readout of the Francis Associates BTs' Thermistor Resistances was obtained by incorporating the BT bridge network within a precision resistance bridge.

The laboratory instrumentation used in reading BT temperature signals was tested and found to provide a reading accuracy and resolution better than an equivalent $\pm 0.02^{\circ}C$.

FIGURE 2.

TEMPERATURE ACCURACY TEST SET UP



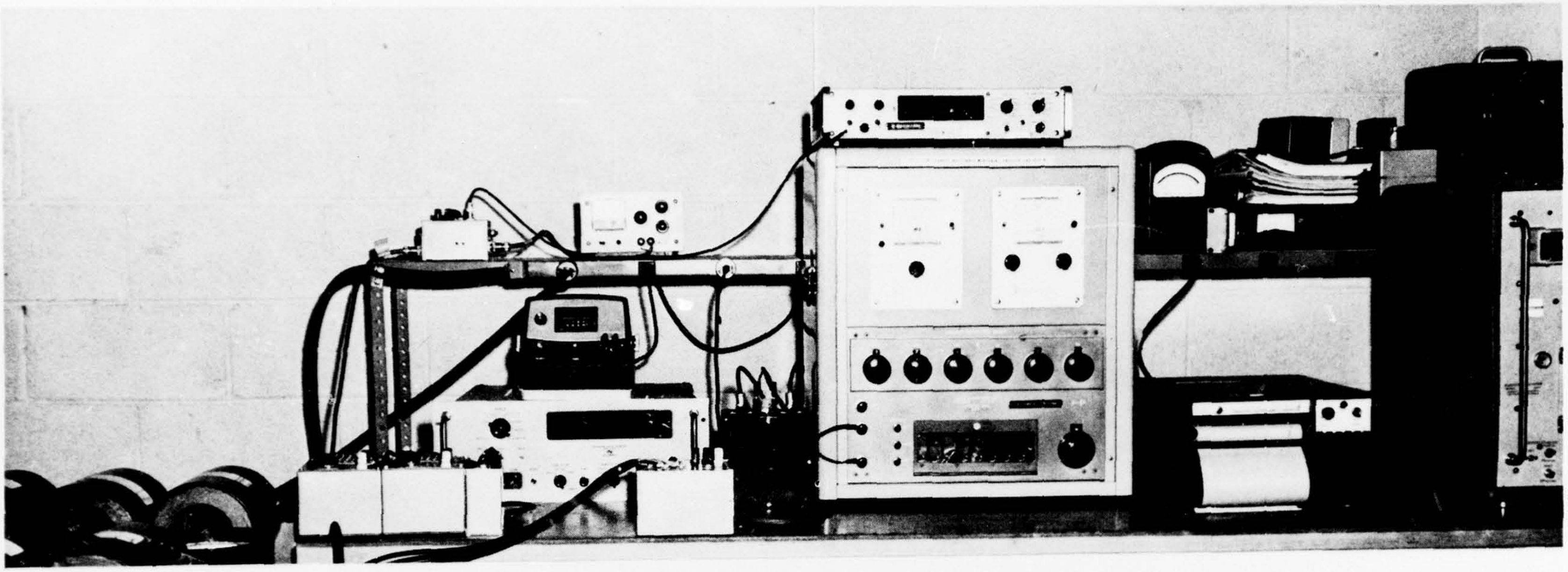


FIGURE 6a - INSTRUMENTATION USED IN TEMPERATURE TESTING

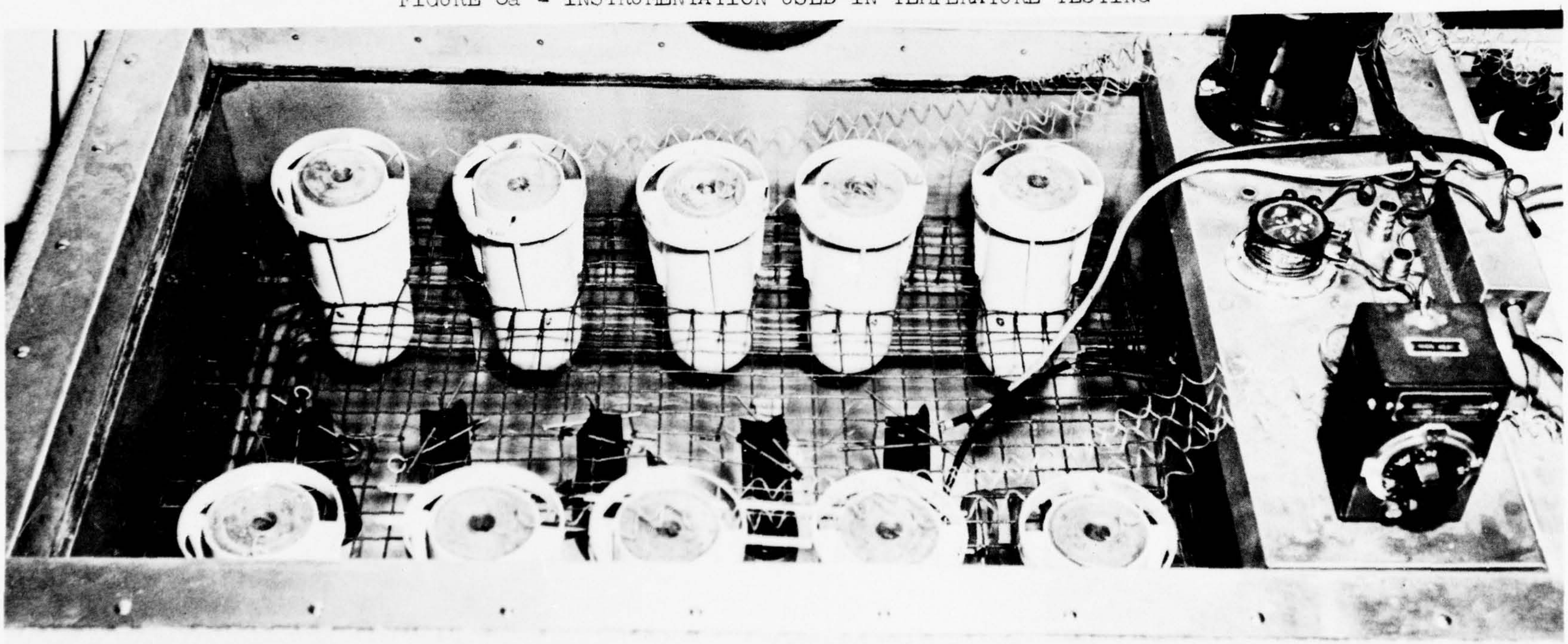


FIGURE 6b - GM AND FRANCIS BTs IN TEMPERATURE ACCURACY TEST TANK

B. Results

Temperature accuracy tests indicate that the General Motors units are within the specified error limits ($\pm 0.20^{\circ}C$) over most of their operating range, ($0-30^{\circ}C$), and that the Francis Associates BTs can achieve the specified accuracy if the manufacturer's calibration is modified.

Temperature errors for the General Motors type "A" units were within the allowable limits except at the extreme upper and lower ends of the operating range ($0-30^{\circ}C$). From $5^{\circ}C$ to $25^{\circ}C$ the General Motors types "A" and "B" units gave temperature readings which are acceptably close to the specified allowable $\pm 0.20^{\circ}C$ error if possible experimental error is considered ($0.04^{\circ}C$ maximum). At the test points of $0^{\circ}C$ and $30^{\circ}C$, however, the temperature error curve extends beyond the allowable error limits.

General Motors supplied a linear calibration factor to be used in converting the voltage outputs of their BT units to temperature readings. The application of this linear calibration factor to the inherently non-linear output of their temperature sensing circuit results in increasing errors as the extremes of the operating temperature range are approached.

Temperature testing of the Francis Associates BT units revealed an average disagreement of about $0.30^{\circ}C$ between the calibration data supplied by the manufacturer and the test data obtained during evaluation. A negative $0.30^{\circ}C$ shift of the entire calibration curve would allow all experimental test points to lie within the acceptable $\pm 0.20^{\circ}C$ error range. Francis Associates believes that this difference was due to poor calibration on the part of the thermistor manufacturer. Thermistor calibration had been corrected on a second group of BT units submitted at a later date for use in field evaluation.

Francis Associates compensates for non-linear thermistor characteristics by balancing the thermistor resistance against a non-linear resistance slidewire within their recording unit. The resulting recorder output is linear over the specified operating range, but the inherent error in the non-linear slidewire unit will increase the BT error as seen from the output side of the slidewire. Tests conducted on the Francis recording unit showed this increase of error within the linearizing unit to be less than $\pm 0.08^{\circ}C$.

Table I and Graphs I, II, and III present the reduced data from temperature accuracy testing.

TABLE I
EXPENDABLE BATHYTHERMOGRAPH EVALUATION
Phase: I. - Absolute Temperature Accuracy - Reduced Data

Taken by: W. Reid   Date: 6 March 1964

Bath Temp. (^{o}C) — Average Absolute Temperature Error (^{o}C)

General Motors Type "A"

BT No.	A4	A7	A8	A9	A10
0	0.15	0.29	0.45	0.48	0.42
5	0.15	0.04	0.15	0.17	0.12
10	0.02	0.14	0.05	0.04	0.01
15	0.03	0.11	0.04	0.04	0.02
20	0.08	0.05	0.08	0.05	0.04
25	0.02	0.12	0.03	0.03	0.04
30	0.20	0.33	0.24	0.27	0.24

General Motors Type "B"

BT No.	B11	B12	B17	B19	B20
0	0.04	0.16	0.06	0.12	0.03
5	0.09	0.03	0.19	0.10	0.13
10	0.10	0.06	0.16	0.06	0.10
15	0.04	0.09	0.04	0.02	0.02
20	0.17	0.23	0.13	0.07	0.11
25	0.08	0.12	0.08	0.03	0.03
30	0.19	0.20	0.23	0.33	0.29

Francis Associates, Inc.

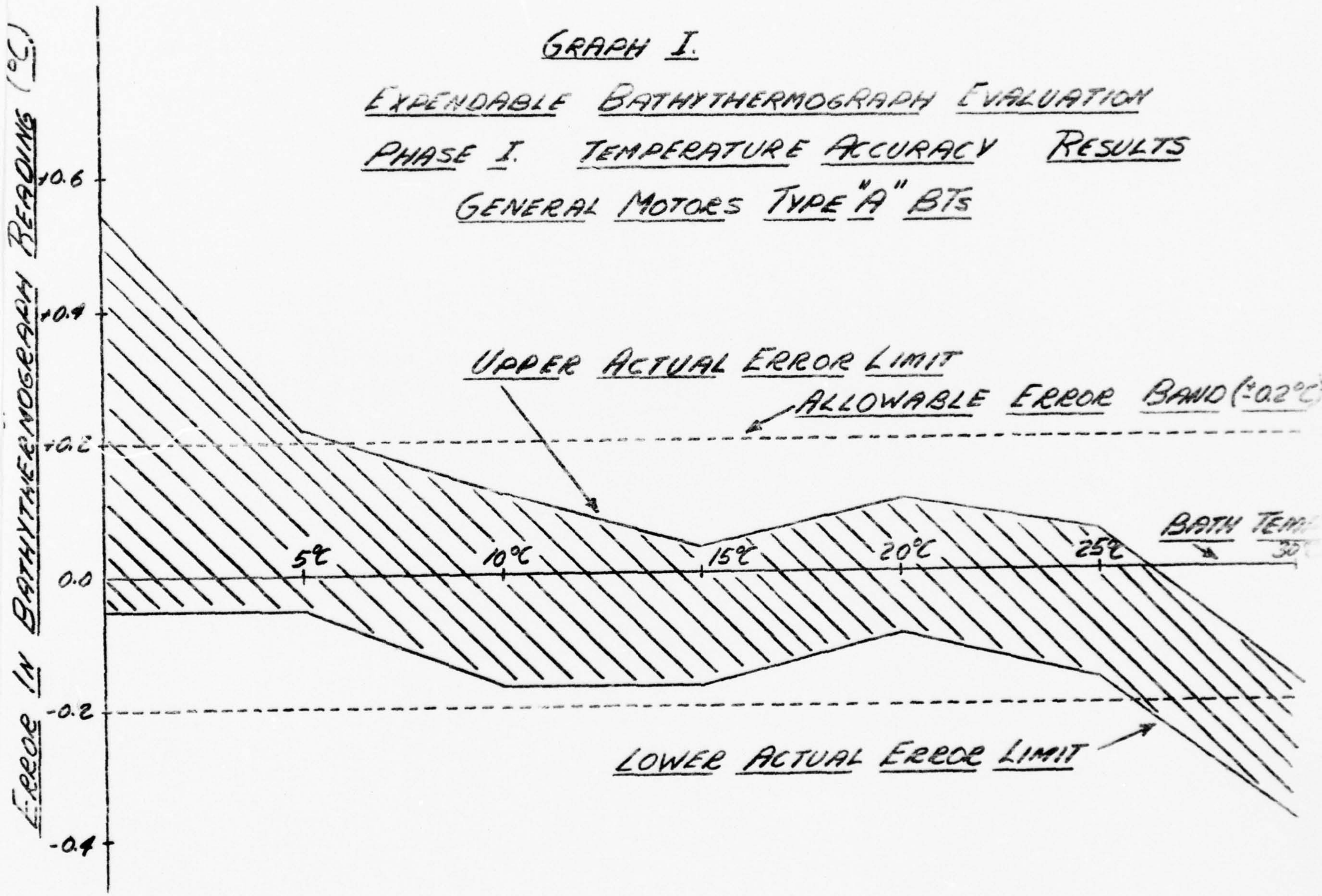
BT No.	A23	A26	A27	A28	A30
0	0.37	0.47	0.37	0.42	0.31
5	0.32	0.41	0.33	0.36	0.28
10	0.28	0.36	0.31	0.30	0.26
15	0.16	0.23	0.21	0.16	0.16
20	0.23	0.27	0.29	0.20	0.23
25	0.28	0.31	0.36	0.24	0.30
30	0.28	0.30	0.39	0.21	0.32

GRAPH I.

EXPENDABLE BATHYTHERMOGRAPH EVALUATION

PHASE I. TEMPERATURE ACCURACY RESULTS

GENERAL MOTORS TYPE "A" BTs

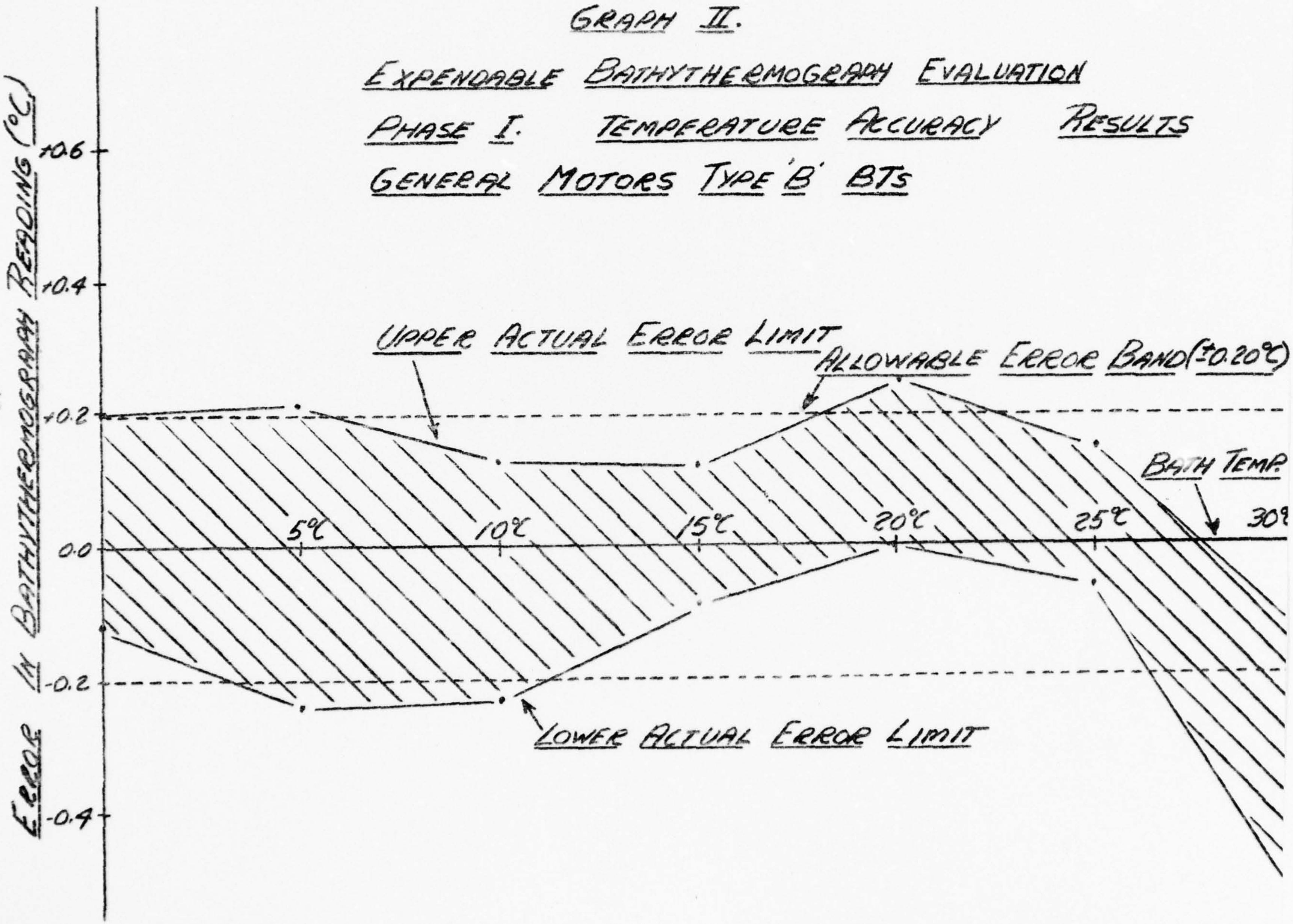


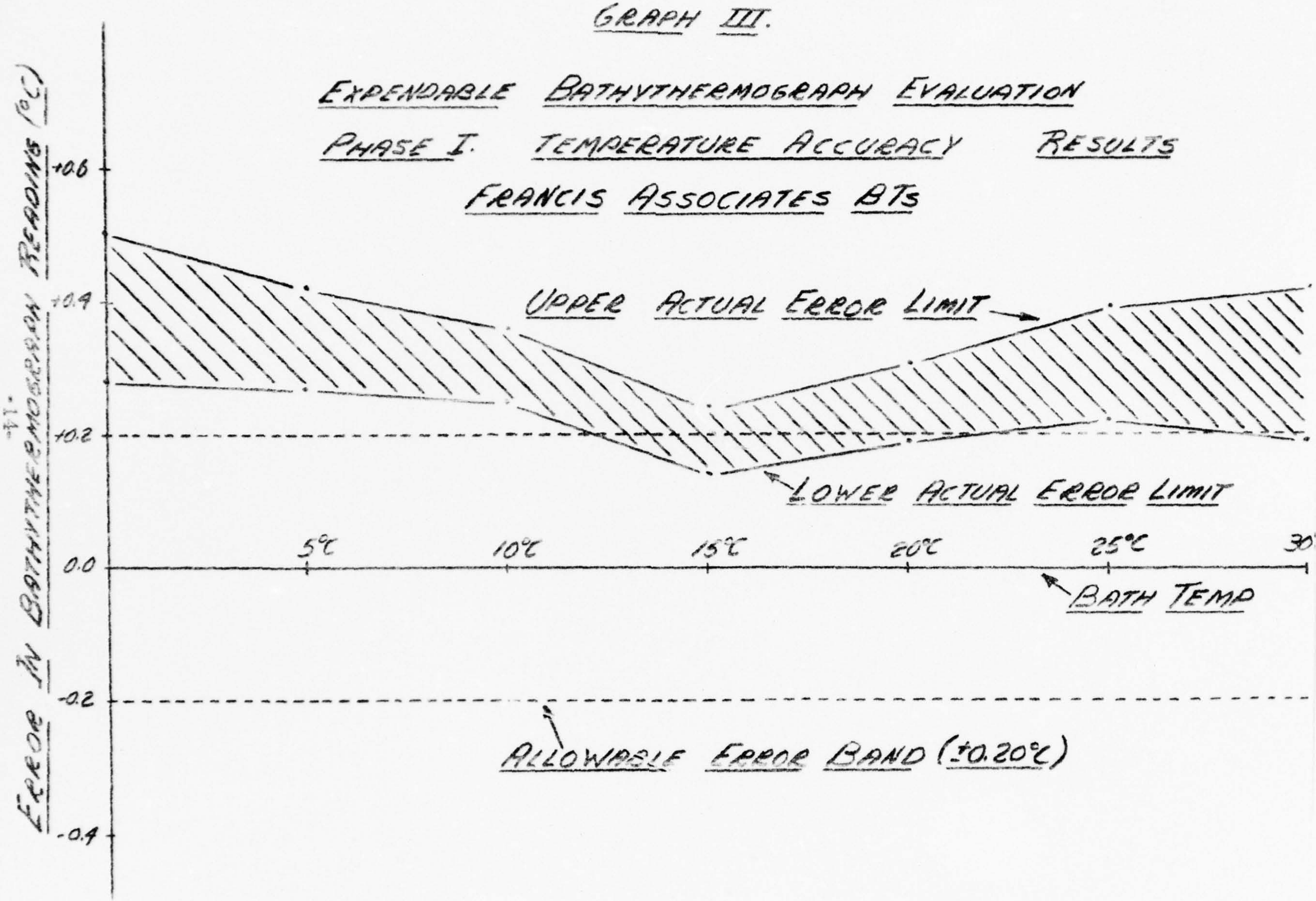
GRAPH II.

EXPENDABLE BATHYTHERMOGRAPH EVALUATION

PHASE I. TEMPERATURE ACCURACY RESULTS

GENERAL MOTORS TYPE 'B' BTs




GRAPH III.
EXPENDABLE BATHYTHERMOGRAPH EVALUATION
PHASE I. TEMPERATURE ACCURACY RESULTS
FRANCIS ASSOCIATES BTs
UPPER ACTUAL ERROR LIMIT
LOWER ACTUAL ERROR LIMIT
BATH TEMP
ALLOWABLE ERROR BAND (±0.20°C)
ERROR IN BATHYTHERMOGRAPH READINGS (°C)
+0.6
+0.4
+0.2
0.0
-0.2
-0.4
5°C
10°C
15°C
20°C
25°C
30

II. THERMAL RESPONSE

A. Test Procedure

The expendable BTs were tested with respect to thermal response to check agreement with the specified 63.2% indication of an instantaneous temperature charge (Thermal Response time constant) within 0.15 seconds.

The method of testing consisted essentially of suddenly changing the temperature of the fluid surrounding the BT thermistor while observing the output of the BT unit on an oscilloscope.

The G.M. types A & B units were tested for thermal response by wetting the BT thermistor and allowing it to come to room temperature equilibrium and then plunging the BT unit into a bath at approximately 8°C above room temperature. The output signal from the BT was recorded on a storage type oscilloscope or photographed from a regular oscilloscope.

Utilizing the same test method, the Francis' units thermal response time constants were found to be in excess of the allowable time of 0.15 sec. In order to simulate actual flow conditions that the Francis BT unit would experience as it descended through water at a thermal velocity of 25 fps, the cold bath into which the BT was plunged was replaced by a stream of cold water forced past the thermistor at approximately 25 fps, thus increasing the heat transfer rate. This method was not used for the G.M. units since their response rate was within specification even in still water.

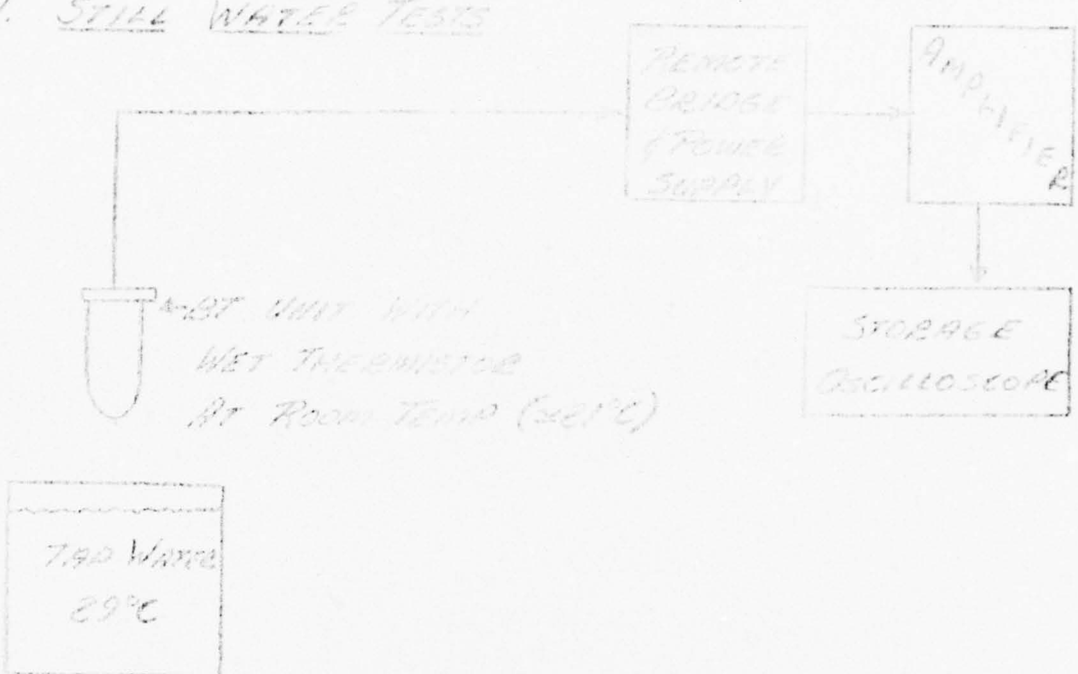
A fast acting solenoid actuated valve was used to provide a sudden surge of cold tap water through a nozzle located directly beneath the nose of the Francis BT unit. By observing the height to which a free column of water would rise from the nozzle, the water pressure was adjusted to provide a flow velocity of 25 fps $\pm$ 1 fps at the nozzle exit. Water was allowed to flow through the valve and nozzle for approximately one minute before each test run to cool the metal surfaces coming in contact with the water down to the 9°C tap water temperature. Water flow was momentarily shunted through a by-pass in the solenoid valve while a Francis BT with a wetted thermistor at room temperature was mounted about one inch above the nozzle. The solenoid valve was then actuated to produce a jet of cold water past the thermistor and the resulting thermal response was observed on a trace-storing oscilloscope which had been triggered simultaneously with the solenoid valve.

Because the recording unit containing part of the Francis Associates BT Bridge circuit was not available until after laboratory testing had been completed, it was necessary to simulate the recorder portion of the Francis' bridge to provide a voltage output from the BT. The voltage output corresponding to thermistor resistance was recorded on a storage oscilloscope which had been calibrated by replacing the thermistor in the BT unit with a decade resistance and observing the bridge output voltage on the oscilloscope screen as the decade resistance was changed to correspond to thermistor resistances at known operating temperatures.

FIGURE I

THERMAL RESPONSE TEST SETUP

A. STILL WATER TESTS



B. WATER JET METHOD

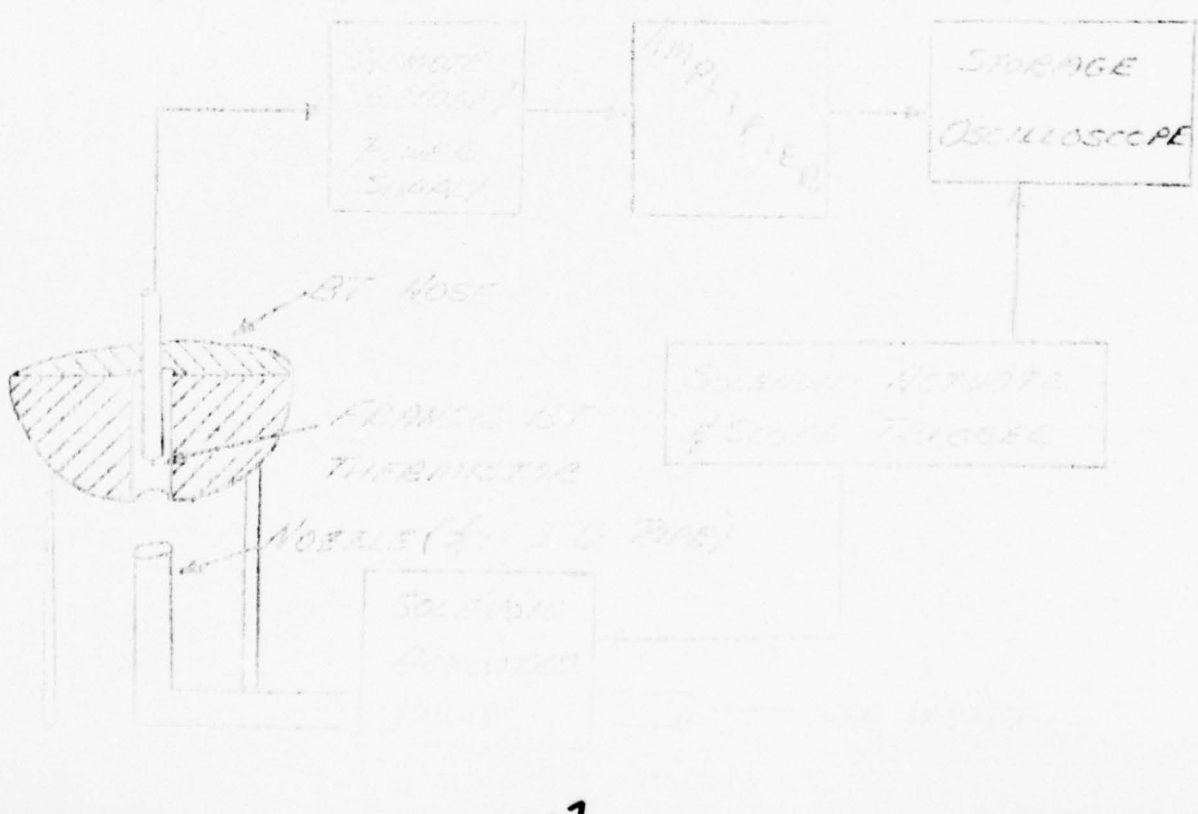


FIGURE 8 - WATER JET TEST FOR FRANCIS BT THERMAL RESPONSE

B. Test Results

Both types of General Motors Expendable BT units demonstrated thermal response time constants below the specified 0.15 seconds when tested in still water. Response time will be somewhat decreased under actual operational conditions since the high flow rate past the thermistor will increase the rate of thermistor temperature change.

Initial still water tests on the Francis BT units indicated a thermal response time ranging from 0.37 sec. to 0.81 sec., depending upon the unit tested. This non-uniformity of response time between BT units was caused by a wide variation in the thickness of the coating material used to insulate the thermistors. When the water jet method described previously was used in thermal response testing, the average response time constant for the units with thinner insulation coatings was reduced to 0.17 sec.

Only slight variations in thermal response time were noted for flow velocities down to about 10 fps, but below that velocity the response time increases sharply with decreased flow velocity.

The thermistors in a group of ten additional Francis BT units submitted for field testing had been modified from the original design used in laboratory tested units. The modified units had more uniform thermistor coatings and thermistor mountings had been modified to eliminate much of the insulating material which appeared to be responsible for the relatively long thermal response time of the originally submitted units.

TABLE II

EXPENDABLE BATHYTHERMOGRAPH EVALUATION

Phase: II - Thermal Response Time Constant - Results

Taken by: W. Reid Date: 25 March 1964

Thermal Response Time Constant	General Motors (Type A)	General Motors (Type B)	Francis Associates Inc.
A. Still Water Test			
Maximum	0.09 sec.	0.11 sec.	0.81 sec.
Average	0.07 sec.	0.08 sec.	0.52 sec.
Range	0.04 sec.	0.05 sec.	0.44 sec.
B. Tests Conducted With 10-25 Fps Flow			
Maximum	———	———	0.19 sec.
Average	———	———	0.17 sec.
Range	———	———	0.03 sec.

III. EFFECT OF PRESSURE ON THERMISTORS

A. Procedure

Erroneous temperature readings could result from stresses induced in thermistor materials at the hydrostatic pressures to which the expendable bathythermograph will be subjected in operational use. To determine the magnitude of temperature error due to pressure effects, the General Motors and Francis Associates expendable BT units were subjected to a pressure (650 psi) corresponding to their maximum operating depth (1500'). The temperature signal outputs were monitored and compared to temperature readings obtained by a pressure-isolated temperature sensing unit (H. R. B. Singer thermistor thermometer). A frame was fabricated to hold the General Motors and Francis Associates BT units so that their respective temperature sensors would be not more than one-half inch from the Singer thermometer.

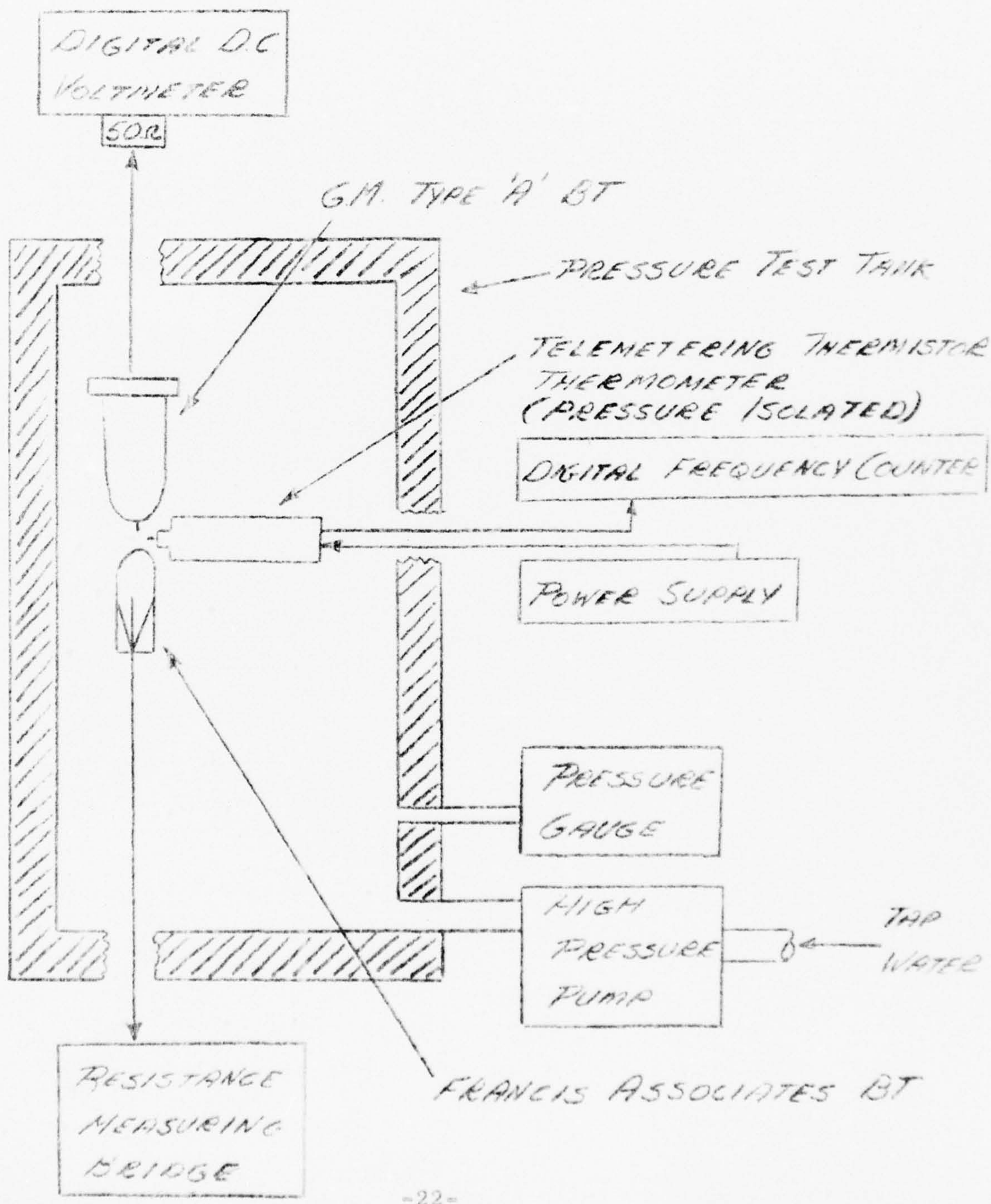
Since all temperature sensors were located within a small region, non-uniformity of temperatures within the test tank could be ignored. The pressure insensitive Singer thermometer eliminated the need for theoretical calculations in determining the actual change of tank temperature due to pressurization.

Temperature readings were taken from the BT units and the Singer temperature sensor at atmospheric pressure. The tank pressure was then increased to 650 psi and the temperature readings repeated.

The change in temperature indicated by the Singer unit was compared to the temperature changes indicated by the BT units to give information as to the effects of pressure on the BT thermistors.

FIGURE 8

PRESSURE EFFECTS TEST SETUP



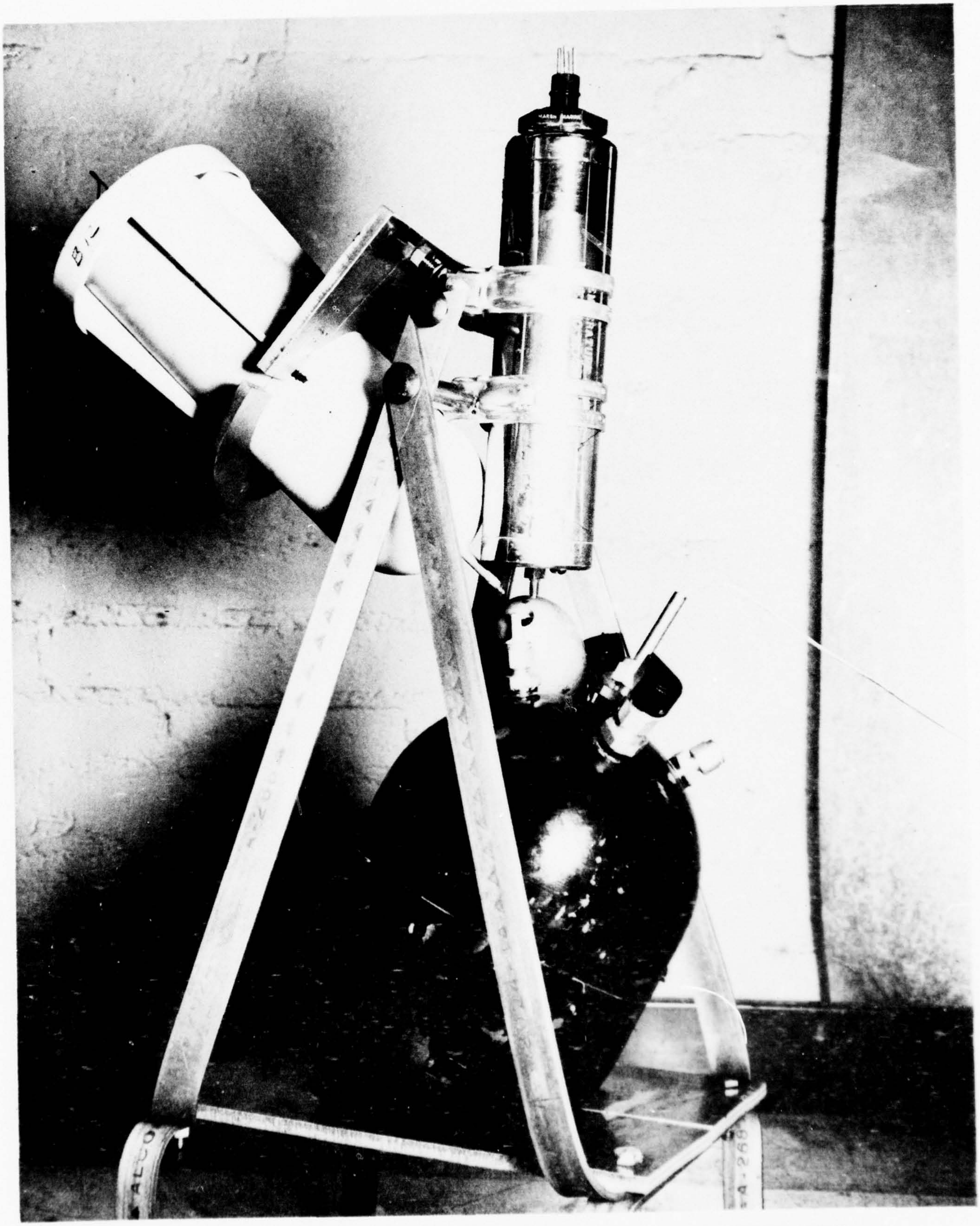


FIGURE 10 - BT SUPPORT FRAME FOR PRESSURE EFFECTS TEST

B. Results

Hydrostatic pressures to 650 psi produce negligible temperature sensing errors in the expendable BTs.

Increasing the bath pressure to 650 psi resulted in a water temperature increase of 0.17°C, as indicated by both the Singer thermometer and the G.M. Expendable BT unit. Any effects of pressure on the thermistor of the G.M. BT unit must therefore be less than the possible experimental error (approximately 0.02°C) involved in testing.

The Francis Expendable BT unit indicated a temperature change of 0.16°C, a difference of 0.01°C from the temperature indicated by the Singer thermometer. Adding the error indicated by the Francis BT to the possible experimental error results in a maximum possible pressure-induced temperature error of 0.03°C. An error of this magnitude can be considered negligible when compared to the ± 0.20°C BT accuracy requirement.

Troubles in the temperature circuit of the Basic Devices, Inc. unit precluded any determination of its pressure sensitivity.

IV. SINK RATE

A. Procedure

Both General Motors and Francis Associates rely on a knowledge of the rate at which their BTs will sink to provide a correlation between the instantaneous depth of the BT and the elapsed time after the BT has entered the water. Since it would be economically impractical to individually calibrate each BT unit in production lots to determine the exact time-depth relationship for the unit, the BTs must be uniform and predictable with respect to sink rate if they are to maintain the specified accuracy in depth measurement (± 15 feet, or 2% of actual depth, whichever is greater).

Some change in sink rate will occur as the BT unit is accelerated from its zero launching velocity and as the deployment of expendable signal conducting wire reduces the BT mass.

Since the number of variables involved in relating time to depth are many, i.e., BT flow characteristics, weight variation between units, change in mass as wire is deployed, launching height, wave height, surface water turbulence, water density, etc., only the apparent major problem areas were selected for involvement in evaluation of the expendable BT concept. The factors selected for experimental analysis included:

1. Terminal BT velocity
   a. Uniformity for a single unit
   b. Consistency between different units of the same type
2. Time (or depth) required to achieve terminal velocity
3. Effect of reduced mass due to wire deployment
4. Effect of variation in launch height.

The Naval Ordnance Laboratory Undersea Weapons Test Tank was utilized in performing sink rate tests on the expendable BTs. This tank is 100 feet deep, 50 feet in diameter, and has a movable platform which may be accurately placed at any desired water depth.

Launching devices were constructed to release the expendable BTs by remote control of solenoid actuated release mechanisms. Trigering switches were provided to accurately determine the time at which the BTs left the launching platform. A hydrophone was mounted on the movable platform to detect the acoustic signal generated when the BTs struck the platform surface. An electronic counter with a 1MC time base was set to start counting on the triggering impulse provided as the BT left the launch mechanism and to stop counting upon receipt of the hydrophone signal.

By this method an accurate indication of the time required for the BT to fall through a known distance was achieved. System response tests indicated an accuracy greater than ± 0.006 sec., equivalent to a BT depth measurement error of less than two inches.

To determine the terminal velocity of the BT units and the variation of terminal velocity between units, three of each of the BT types submitted for evaluation were dropped five times each through water depths of 25, 50, 75, and 100 feet. The times required to reach the respective test depths were recorded and used to provide velocity data through analysis of the time intervals between subsequent depth levels.

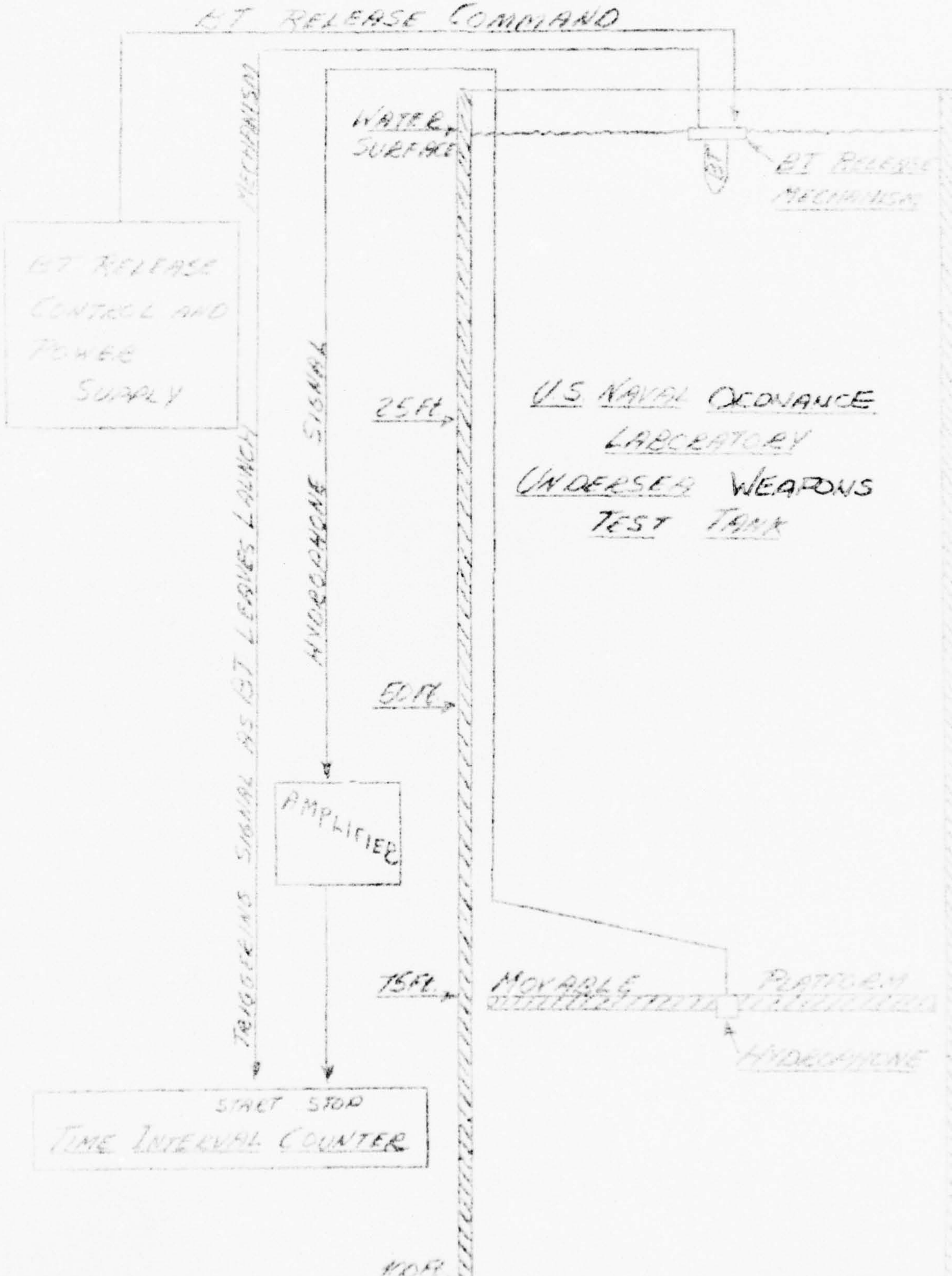
No wire was deployed from the BT units during the first series of tests because the purpose of the tests was to compare terminal BT velocities under identical mass conditions. The effect of wire deployment was then determined by dropping each BT through the full 100' test depth with wire being deployed.

All of the wire in one BT unit of each type was then removed and the BT used to repeat the first series of drop tests to determine the change in terminal velocity due to the loss of wire mass.

A series of tests was planned in which the BTs would be dropped from varying heights to determine the effect of water surface impact upon the BTs' velocity, but the hydrophone cable was severed by a BT unit before the tests could be completed.

FIGURE 11

SINK RATE TEST SET UP



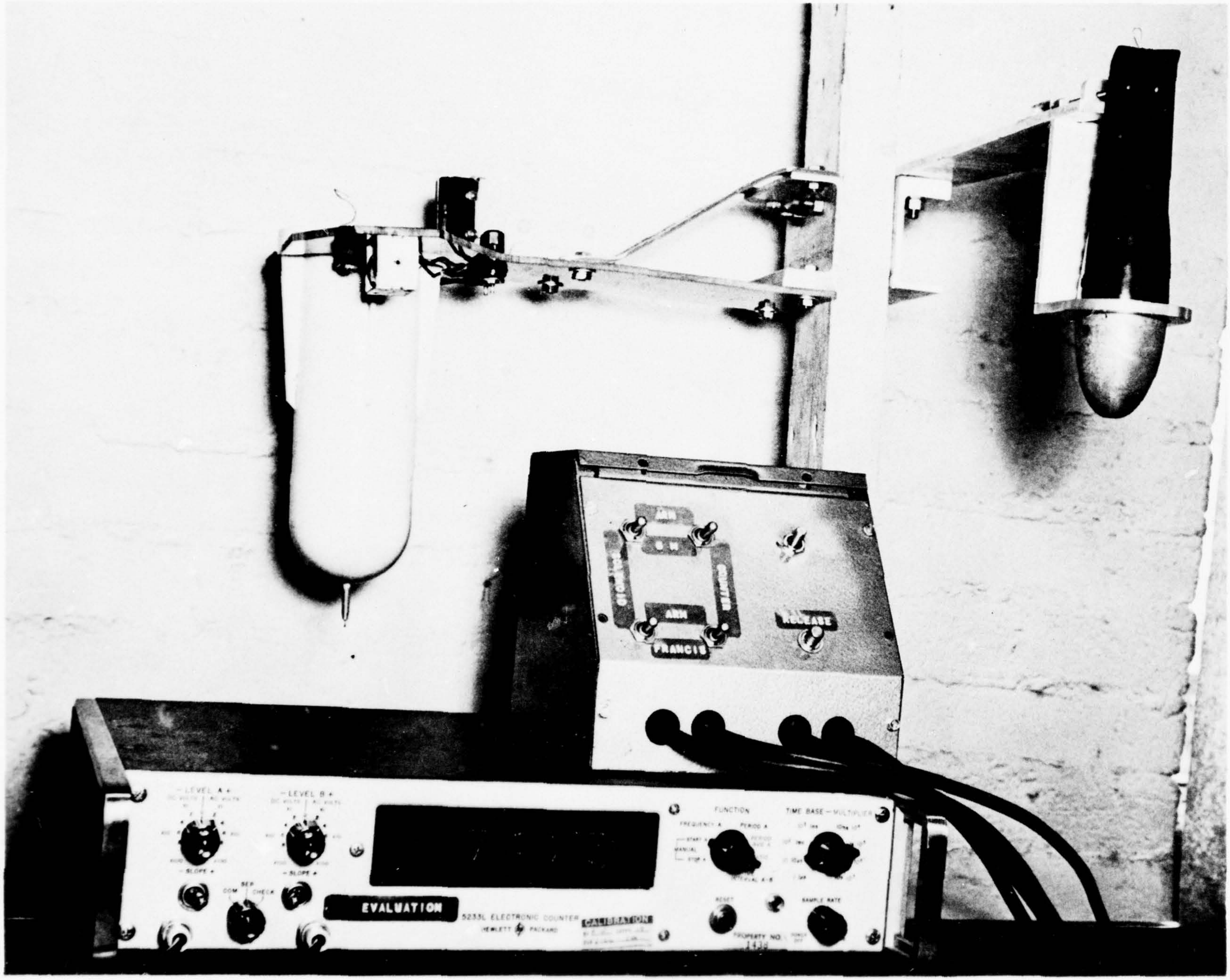


FIGURE 12 - BT RELEASE MECHANISMS AND TIME INTERVAL COUNTER USED IN SINK RATE TESTING

B. Results

Sink Rate tests performed on General Motors and Francis Associates Expendable BTs indicated that the required depth accuracy (± 15 feet or 2%) can be achieved, but that the attainment of this accuracy will require precise control of weight and dimensional tolerances of production BTs as well as an accurate analysis of the many factors affecting sink rate.

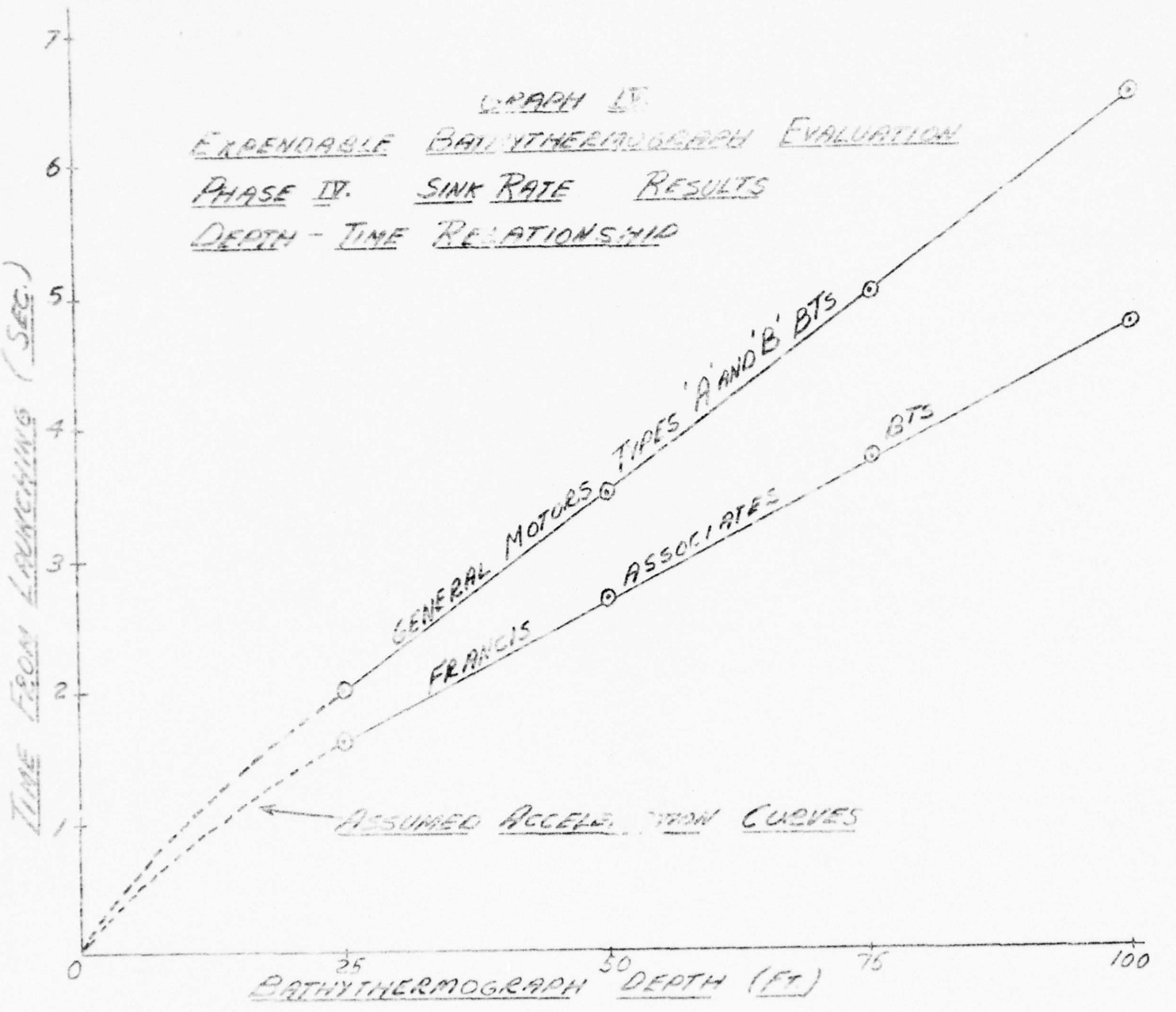
The results of sink rate evaluation tests performed at the N.O.L. Undersea Weapons Test Tank are as follows:

BT type	General Motors Type A	General Motors Type B	Francis Associates
a. Average terminal velocity	16.2 fps	16.1 fps	25.4 fps
b. Maximum deviation in average velocity for a single unit in 5 drops of 100 ft. each	0.3%	0.5%	0.7%
c. Maximum variation in average terminal velocity between 3 units	1.3%	3.8%	2.1%
d. Deviation in terminal velocity when deploying wire	negligible - less than 0.2%		
e. Change in terminal velocity due to loss of all signal cable mass	-2.0%	-2.2%	-4.3%
f. Distance required to attain terminal velocity when launched at water surface	less than 25 feet		

The degree of terminal velocity correlation between identical units would be better than that indicated by these tests if the units could have been kept in their original condition throughout the testing period. Impact of the units with the tank platform caused some damage to each of the BT units after repeated test drops. Although the damage to the units was relatively minor, some error was induced in subsequent tests due to changes in flow characteristics in the case of damaged BTs.

The maximum terminal velocity variation between identical BT units was less than 4%. To meet the depth specification of ±2% accuracy, it may be necessary to correct for the effect of mass reduction due to signal wire deployment, launch height, and to precisely index the instant of impact. The limit of the effects of in-situ conditions on the terminal velocity are not precisely known at this time.

These tests were performed in fresh water; a slightly different terminal velocity is anticipated in salt water. The respective BT manufacturers are presently engaged in further experimental and theoretical analyses of sink rate characteristics. Until final time-depth relationships have been submitted by the manufacturers, thorough analysis of depth accuracy parameters is beyond the scope of the present evaluation program. Some additional indication of BT depth accuracy is provided by the field evaluation phases of this report.


GRAPH IV
EXPENDABLE BATHYTHERMOGRAPH EVALUATION
PHASE IV. SINK RATE RESULTS
DEPTH - TIME RELATIONSHIP
GENERAL MOTORS TYPES 'A' AND 'B' BTS
FRANCIS ASSOCIATES BTS
ASSUMED ACCELERATION CURVES
TIME FROM LAUNCHING (SEC.)
BATHYTHERMOGRAPH DEPTH (FT)
0
25
50
75
100
1
2
3
4
5
6
7

V. ON STATION AND LOW SPEED TESTING

A. Procedure

Expendable BT units were evaluated at sea aboard the USNS GILLISS to consolidate all phases of testing performed in the laboratory and to provide a final testing stage under actual operational conditions.

An important requirement of the field testing program was the availability of reliable data on temperature-depth relationships in the testing area. The USNS GILLISS was chosen as a testing facility because of its Nansen cast capability. The low speed tests included underway testing up to 12.5 knots. Further tests at speeds up to 25 knots were conducted during Phase VI of the evaluation.

Ten each of the Francis Associates and General Motors type B expendable BTs and three each of the G.M. type A and Basic Devices, Inc. units were utilized in field testing. In addition to the BT units, both General Motors and Francis Associates supplied strip chart recorders and launching facilities for use in the field evaluation program. General Motors utilized an oscillograph to record the BT signals. A support stand for the G.M. shipboard cable canisters was also supplied.

Francis Associates supplied a Bristol strip chart recorder which had been modified by the addition of a non-linear resistance slidewire to compensate for the nonlinearity of their BT thermistor element. The Francis BT launching unit consisted of a six-foot tube which could be mounted to any convenient railing or stanchion aboard ship. Launching of the Francis BT was accomplished by placing the unit within the breech of their launching tube and retracting a pin that held the BT within the shipboard cable canister.

The X and Y axes of a Mosely X-Y recorder (Model 2D) were used to record the pressure and temperature signal outputs of the Basic Devices expendable BTs. The Basic Devices units were supported from a BT winch boom and were launched by severing a cord which detached the BT from a shipboard cable canister. Since the Basic Device units had not been laboratory tested, an attempt was made to temperature calibrate the units before launching. By placing the BTs alternately in a pail of cold and warm water, calibration points were established directly on the X-Y recorder. Preliminary laboratory pressure tests had supplied pressure correlation data which was utilized in establishing pressure axis on the recorder.

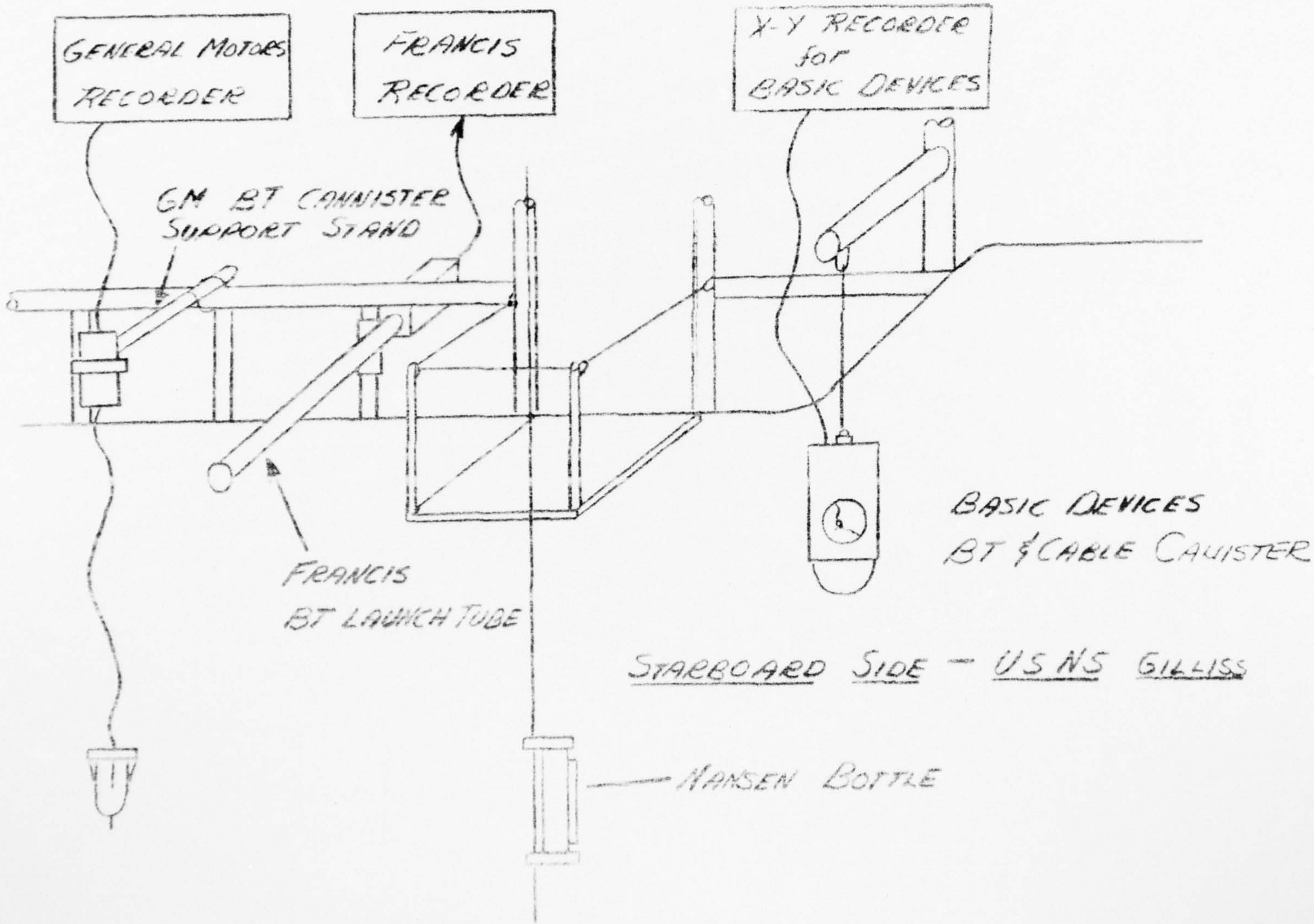
Since the data recording units supplied by G. M. and Francis Associates are not necessarily similar to the equipment which will be used in conjunction with production BTs, precautions were taken to insure that fluctuations in shipboard power supply would not be detrimental to the data recording process. Line voltage regulation to 117v ± 1v and frequency regulation to 60 cps ± 0.1 cps were provided for the Francis recorder. The synchronous motor chart drive of the Francis recorder causes chart speed to be directly dependent upon line frequency and thus depth (timing) accuracy is directly dependent upon the frequency regulation available on board a given ship. The G. M. recorder provides timing lines which are independent of line frequency.

Since the major purpose of the field evaluation program was to provide data on the accuracy of temperature-depth profiles produced by the expendable BTs, most tests were conducted on station where a reliable temperature-depth profile supplied by Nansen casts could be compared to the BT data. A region of relatively stable temperature conditions was selected as a test station. The expendable BTs were tested over a three-hour period with Nansen casts taken before and after the test period to provide data on the temperature stability of the water mass. Seven G. M. BTs, seven Francis Associates BTs, and three Basic Device BTs were deployed during this time interval.

The remaining BT units were deployed from the GILLISS at 12.5 knots to provide data on underway operation. Three Francis units and three G. M. units were deployed during a fifteen-minute period before the GILLISS was scheduled to take an oceanographic station. The underway tests were conducted on the edge of the Gulf Stream in a region of sharp thermoclines. All BTs were deployed within three nautical miles and one-half hour of a reference Nansen cast station. The data provided by the expendable BTs in the underway tests was not expected to agree exactly with Nansen cast data because of the relatively unstable water temperatures. The data was used to analyze BT indication of a sharp thermocline and to check general correlation with presumably stable deep water temperatures.

FIGURE 13.

FIELD TEST EQUIPMENT ARRANGEMENT



B. Results

The expendable BT tests conducted with the GILLISS hove-to showed, in general, correlations between GM and Francis BT and Nansen cast data within the accuracy ranges specified for the expendable BTs. Three profiles to the designed maximum operating depth of 1500 feet. The other three units provided accurate data to over 700 feet before the BT signal became erratic. The temperature traces produced by the three BT units which did not operate correctly to full rated depth showed continuous temperature profiles down to a point on the trace where the recorded signal was sharply deflected and showed highly erratic behavior. This erratic behavior was probably caused by sea water leakage through the signal cable insulation.

On-station testing of the Francis BT units provided satisfactory temperature profiles over a limited depth range. Only one of the Francis units succeeded in operating to the full 1500 foot depth. The five other units each showed a characteristic sharp offset in the temperature profile at depths ranging from 450 feet to 1100 feet. When the Francis units were used on-station, wire from the shipboard cable canister tended to pay out on the water surface in small coils which may have produced kinks as the wire was pulled beneath the sea surface. Short circuits produced by kinking of the signal cable would explain the sharp trace displacements noticed on most of the Francis BT temperature profiles. When the BTs are deployed from the shipboard cable canister prevents the formation of loops in the wire and thus the problems noted in on-station testing should not be present when underway. This theory is supported by the fact that all three of the Francis BTs which were deployed at 12.5 knots achieved 1500 foot recording depths without apparent problems.

The three Basic Device expendable BTs tested on-station did not produce any useful data. Although the units appeared to operate properly when tested on deck, the deployed units produced temperature and depth signals bearing no relationship to the conditions actually present.

Francis and GM expendable BTs were also deployed at a speed of 12.5 knots to determine underway operational characteristics. All three of the Francis units used underway produced temperature profiles which correlated satisfactorily with a Nansen cast taken later in the same general test area.

Underway deployment of the GM BT units revealed a problem in maintaining signal cable continuity as the BT units impaced on the water surface. Of the three GM units tested underway, only one unit continued to transmit temperature signals after launching. It is believed that the signal failures were caused by excessive cable stresses in the region where the BT and shipboard cables are joined and connected to a surface float unit.

Low speed test results are presented in Table III and the sample expendable BT temperature profiles.

TABLE III

EXPENDABLE BATHYTHERMOGRAPH EVALUATION

Phase: V - Field Testing - Results

Comparison of Nansen Cast Data to Expendable BT Temperature-Depth Profiles

I. On Station Tests - 10 June 1964

A. Francis Associates

Nansen Cast Data	Temp. (°C)	A-65	A-66	A-68	A-69	A-80	A-81
0	24.25	-0.10	+0.10	+0.10	0.00	0.00	+0.10
30	23.90	+0.15	+0.10	+0.05	+0.15	+0.50	+0.05
60	23.29	+0.05	0.00	0.00	+0.10	+0.05	+0.20
100	21.60	0.00	-0.05	+0.10	+0.05	+0.10	0.00
150	20.43	-0.20		-0.10	-0.05	+0.20	0.00
200	19.44	-0.10		0.00	0.00	+0.15	-0.05
250	18.83				-0.10	+0.20	-0.15
300	18.36				-0.10		-0.20
350	18.17				-0.20		
400	18.06				-0.15		
450	17.93				-0.05		
Maximum depth-----		700'	430'	620'	1500'	900'	1100'

B. General Motors

Nansen Cast Data	Temp. (°C)	B-27	B-28	B-29	B-30	A-5	A-6
0	24.25	-0.30	-0.05	-0.25	-0.20	-0.25	0.00
30	23.90	-0.15	-0.20	-0.10	-0.10	-0.05	-1.00
60	23.29	0.00	+0.05	0.00	0.00	-0.15	-0.30
100	21.60	0.00	+0.10	-0.25	-0.05	-0.15	-0.30
150	20.43	+0.20	-0.05	-0.05	-0.05	-0.10	-0.40
200	19.44	-0.05	-0.10	-0.10	-0.05	-0.10	-0.40
250	18.83	0.00	-0.10	-0.05		-0.05	
300	18.36	0.00	-0.05	-0.05		0.00	
350	18.17	-0.10	-0.05	0.00		0.00	
400	18.06	-0.10	-0.05			0.00	
450	17.93	-0.10	-0.05			0.00	
Maximum depth-----		1500'	1500'	1150'	710'	1500'	720'

II. Underway Testing - 12 June 1964

A. Francis Associates BTs

Ship speed: 12.5 knots

Units tested: A-83, A-84, A-85

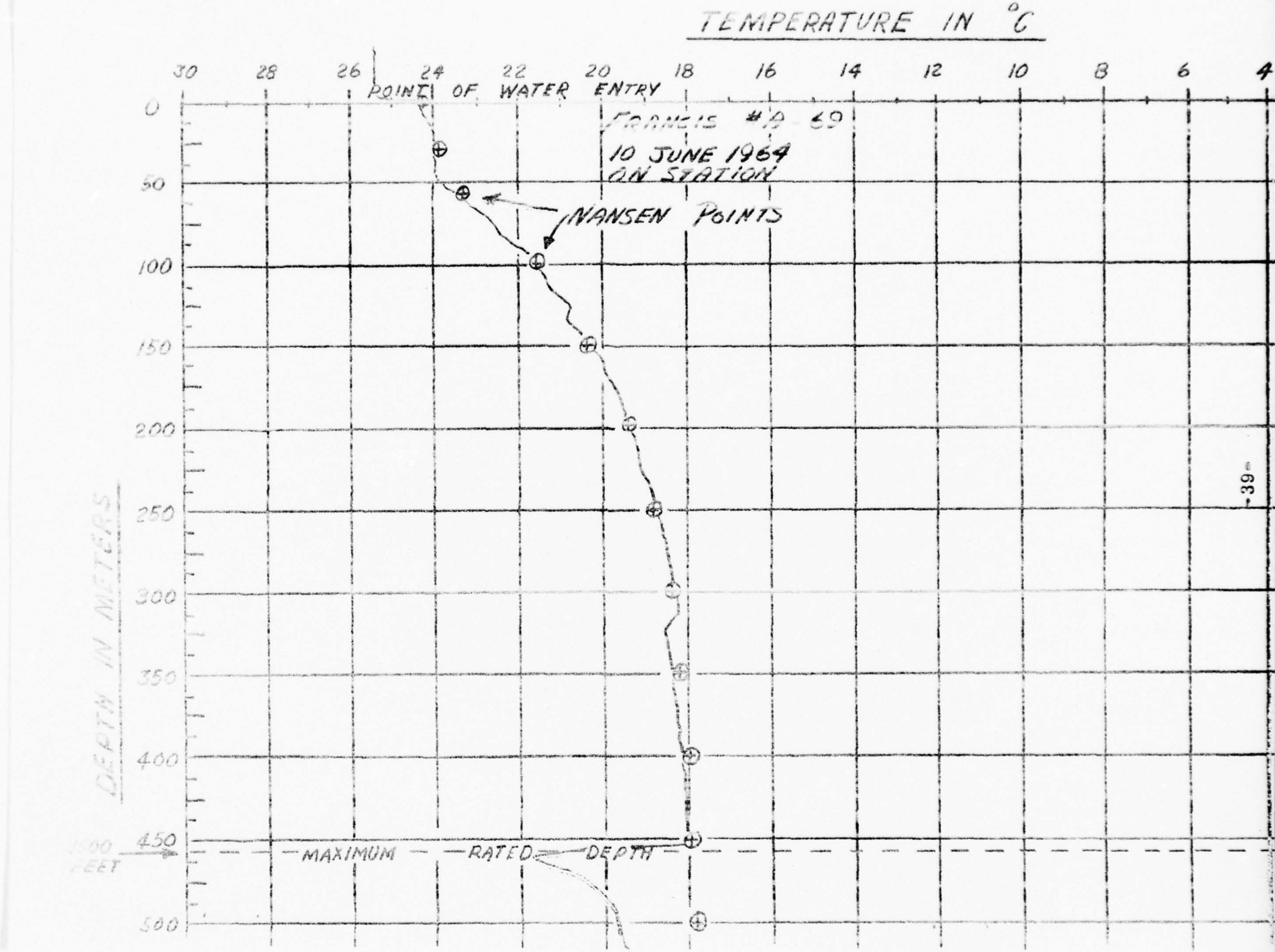
Results: All three units operated satisfactorily through the designed depth range of 1500 feet. Indication of the sharp thermocline present at the testing area appeared excellent. Nansen cast data indicated a temperature-depth profile in the deep water regions similar to that obtained with the BTs.

B. General Motors BTs

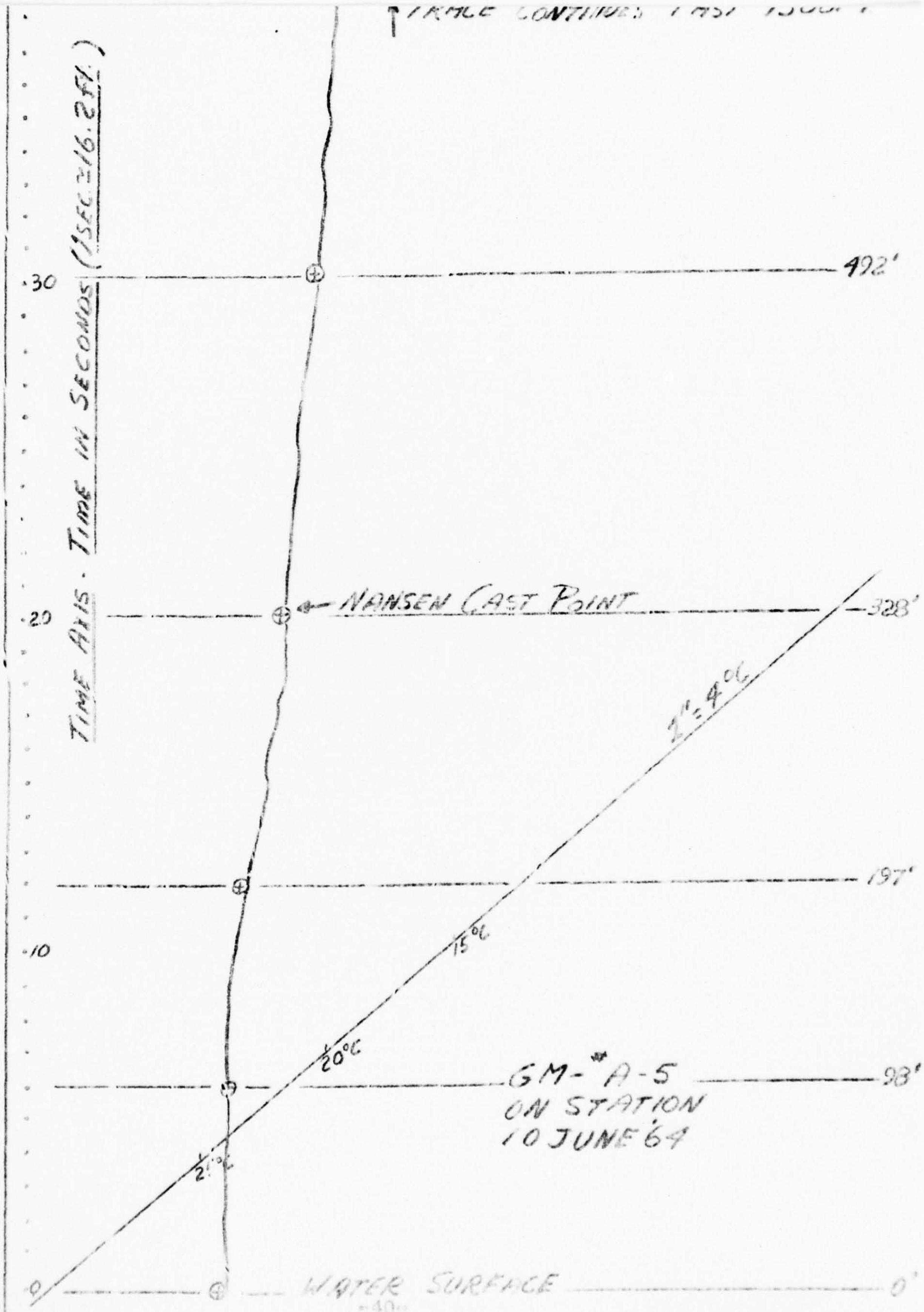
Ship speed: 12.5 knots

Units tested: B-22, B-23, B-25

Results: Unit B-22 functioned properly to a depth of 60 feet. Units B-23 and B-25 stopped operating on water impact.



TEMPERATURE IN °C
30
28
26
24
22
20
18
16
14
12
10
8
6
4
POINT OF WATER ENTRY
FRANCIS #A-69
10 JUNE 1964
ON STATION
NANSEN POINTS
DEPTH IN METERS
0
50
100
150
200
250
300
350
400
450
500
1500 FEET
MAXIMUM RATED DEPTH


TRACE CONTINUES PAST
TIME AXIS · TIME IN SECONDS (1SEC=16.2FT.)
30
20
10
0
492'
NANSEN CAST POINT
328'
2"=4°C
197'
15°C
20°C
GM-#A-5
ON STATION
10 JUNE 64
98'
21°C
WATER SURFACE
0'

VI. HIGH SPEED FIELD TESTING

A. Procedure

Expendable BT tests covered earlier in this report had been concerned primarily with concept feasibility. Units developed by General Motors and by Francis Associates demonstrated the ability to produce accurate temperature profiles at low to moderate speeds, though some problems tended to limit overall performance. A second series of field tests, involving higher operating speeds and more severe environmental conditions, was conducted to provide further information on the overall capabilities of the BT systems.

At present, there is no capability for accurate determination of temperature profiles while operating at high speeds (20-30 knots), although an accurate determination of the ocean temperature profile, for comparison purposes, could have been obtained from reversing thermometers, vessel scheduling limited the high-speed testing phase to the use of a U. S. Navy Destroyer on a "not to interfere" basis with the limited comparison data supplied by mechanical BTs and salt water injection temperature readings.

Previous field testing indicated that radical departures from accurate temperature profiles would be accompanied by erratic recording of expendable BT data (see sample BT traces, pgs. 39 and 40). Analysis of the BT data was therefore based on the continuity of temperature profiles and on comparison of traces obtained by several expendable BTs, all dropped during a short time interval. Although no absolute determination of the existing ocean temperature structure was made, analysis of the expendable BT traces with reference to information obtained during previous tests provided a good indication of high speed operational characteristics.

Prior to the test, five of the originally submitted type "B" (shipboard power supply) and two of the type "A" (self-contained power supply) expendable BT units were returned to General Motors at their request. These units were subsequently modified to provide improved signal cable continuity. Modifications consisted of rounding off the edges of the surface float (Fig. 3, pg. 4) and providing a protective sheath of plastic tubing around the signal cable in the region where the shipboard and BT signal cables are connected to the float. In addition, a short length of protected signal cable from the shipboard cable bail was coiled within the float unit to partially absorb water surface impact shock. Six additional type "B" units were supplied to bring the total number of

General Motors BTs available for high speed testing to thirteen. Eleven Francis Associates expendable BTs, including six new units, were also utilized during this test phase.

The expendable BTs, their associated recording and launching equipment, and various items of test equipment were loaded on board the USS SAUFLEY (DD 465) in New York. The BT recorders were set up in the SAUFLEY's torpedo room, located approximately amidships on the main deck. The Francis Associates expendable BT launching tube was mounted directly opposite the port torpedo room hatch, with the tube facing 45 degrees forward from the stern and depressed 45 degrees from the horizontal. Calibration checks were made on the strip chart recorder supplied by Francis Associates and on General Motors' oscillograph. Both BT signal recorders were operated on the ship's 110 volt, 60 cycle power supply. An isolation transformer was provided for use with Francis Associates' strip chart recorder, but was found not to be necessary for satisfactory operation.

The ship's power was continuously monitored during the BT tests. Line frequency was found to be regulated to 60 cps $\pm$0.5 cps; voltage remained within a range of 112 volts $\pm$5 volts. The crystal controlled timing mechanism of General Motors' oscillograph can tolerate ranges of 115 volts $\pm$10 volts, and 60 cps $\pm$5 cps without adverse effect upon data accuracy. Since the synchronous chart drive motor in Francis Associates' recorder relates chart speed directly to line frequency, the $\pm$0.5 cps deviations in the ship's power supply would produce errors up to $\pm$ 0.8 per cent in the BT trace depth accuracy.

As in previous tests, General Motors BT units were launched by throwing the connected BT and surface float as far outboard as possible while holding the shipboard cable canister over the ship's side. The Francis Associates BT units were deployed through the Francis Associates launching tube.

All Francis Associates BT units were equipped with a three-conductor signal cable, one of the conductors being used as a ground return. Provision has been made in the Francis Associates BT system to eliminate the third conductor by using a sea water return from the BT unit to the ship's ground. The two-wire mode of operation has the advantage of reduced BT cost and provides automatic recorder operation by triggering the recorder chart drive when the BT unit makes contact with the water surface. Both the two-wire and the three-wire modes of operation were tested.

The expendable BTs were tested over a six-day period at varying speeds and in varying sea states. Initial testing was conducted at 25 knots in calm seas. Because the USS SAUFLEY's operational schedule did not involve subsequent high-speed operation, all remaining tests were performed at speeds below twenty knots. The sea remained relatively calm until the last day of testing, when conditions up to sea state five were encountered.

Analysis of data was based primarily on comparison of multiple BT traces obtained during short time intervals and on observation of expendable BT trace behavior. Any appearance of highly erratic behavior in the BT trace was judged to terminate the useful portion of the temperature profile. Though mechanical BT traces and sea water injection temperatures were obtained wherever possible, the dubious accuracy of these measurements rendered them unsuitable for use in analysis of the expendable BT traces.

B. Results

1. Francis Associates

The eleven Francis Associates expendable BTs deployed during the high speed test phase operated successfully to an average depth of 930 feet. Seven of the Francis Associates BT units were launched at 25 knots in calm seas and yielded good temperature profiles to an average depth of 950 feet. The remaining four units were deployed at 18 knots in state five sea conditions and operated on the average to 900 feet. Both the regular three-conductor circuit and the sea water ground two-wire system were utilized in testing of the Francis Associates units with no discernible difference in performance.

Installation and operation of the Francis Associates expendable BT system were relatively easy and required only limited operator training. The recorder can be placed anywhere on board ship where a 110 volt, 60 cycle power supply and protection from the weather are available. A small bracket attached to a stanchion on deck provides support for the launch tube. The launch tube can be removed or attached to the bracket by one man in less than a minute. A single multi-conductor electrical cable connects the BT launch tube to the recorder. Operation of the system consists of turning the recorder on, allowing about five minutes for warm up, sliding the expendable BT canister into the launch tube breech, closing the breech, and pulling a pin to release the BT. In the two wire mode of operating contact between the BT ground and the water surface automatically starts the recorder chart in motion. A finished trace can be removed from the recorder immediately upon completion of the drop (approximately one minute after BT launching). Deployment of the Francis Associates BT can be easily accomplished even in heavy weather, though care must be exercised to insure that the electrical contacts within the launch-tube breech do not become short-circuited by salt water spray. Installation of the launch tube on the lowest accessible deck is desirable to avoid the problem of having a cross wind carry the signal cable into contact with the hull or superstructure.

Francis Associates supplied a mylar plastic overlay sheet containing temperature and depth scales to facilitate the interpretation of their BT traces. Since temperature and depth calibration factors are identical for all units, the calibration grid could be printed directly on the BT chart paper.

The one-second full scale response of the recorder presently used by Francis Associates appears adequate when compared to the probable maximum rate of temperature change with increasing depth in the ocean. Since the recorder scale covers 32°C and the BT probes sink at approximately 25 feet per second, the maximum recording rate for any temperature change is 32°C in 25 feet or 1.3°C per foot of depth. System response tests, conducted by replacing the thermistor of a Francis Associates BT probe with a decade resistance, showed that the recorder responds at a constant rate to any step resistance change and indicates the final resistance (temperature) with little or no overshoot.

2. General Motors

The modified General Motors expendable BT units performed significantly better than earlier models tested during Phase V of the evaluation. Some signal transmission problems were still present, as evidenced by the relatively poor performance of three units tested at 25 knots, but three of the six new (serial B31 through B36) General Motors units operated to the full 1500 foot designed depth at a ship speed of 15 to 18 knots. Reliability of the new General Motors units was, in general, superior to that of the modified older units (see Table IV, Pg. 47). Both the new expendable BTs and the older units had been modified from the originally submitted models to provide greater signal cable protection in the surface float region. The only difference between the new units and the modified old units was the greater length of protected signal cable coiled within the float of the newer BTs. The results of this series of tests indicated that the new units out performed the older BTs. Maintaining signal cable continuity at the surface float junction, however, still appears to be a major problem. The shipboard and BT unit cable bails allow free pay out of signal cable in underway operation, but attachment of the cable to a float produces a condition where the cable will be stressed if any force is applied to the float. The floats of two of the General Motors units were removed and the BT units were deployed at 25 knots to determine if the float units were responsible for some of the failures noted at high operating speeds. The two units attained operating depths of 450 and 385 feet. The one unit deployed at 25 knots with its float intact stopped operating upon impact with the water surface.

Several of the temperature profiles obtained with General Motors BTs show highly erratic signal behavior. In most cases, this erratic behavior is exemplified by a high noise level superimposed upon an apparently normal trace, followed by sharp trace displacements at greater depth. The noise occurring in these traces is actually a series of sharp random displacements of varying amplitude and could be explained by intermittent shorting of the signal cable through small leaks in the cable insulation. Sharp permanent trace displacements would more probably be caused by complete resistance breakdowns or by actual parting of the signal cable.

The rapid thermal and recorder response rates of the General Motors expendable BT system combine to provide a good indication of water surface temperature even in cases where the air temperature differs substantially from surface water temperature. Since the thermal response time constant of General Motors BT units is approximately 0.08 seconds, 63 per cent indication of an instantaneous temperature change (air temperature to water temperature) is obtained in 1.3 ft. when the BT descends at its thermal velocity of 16 fps. As long as air and water temperatures differ, the point at which the BT entered the water will be clearly indicated by a sharp temperature profile deflection, thus defining the water surface on the finished BT trace.

The temperature analog DC output of General Motors BT units allows, with suitable amplification, the use of a wide variety of common recorders or indicators for signal readout. An optical recording oscillograph was supplied by General Motors for use in evaluation of their BT system. The oscillograph offers a major advantage in that the low level signal from the BT unit is used to drive a galvanometer directly without any amplification. During the course of high speed testing, the mercury vapor oscillograph light source burned out. Since no spare bulbs were available, a flashlight bulb was placed in the lamp housing and used to project a light spot on the photographic recording paper. The spot was manually traced onto the recording paper in pencil.

Photographic BT traces produced by the oscillograph presented some handling problems. Exposure to direct sunlight darkens the recording medium. A chemical fixing process is required to permanently protect the light sensitive paper from darkening.

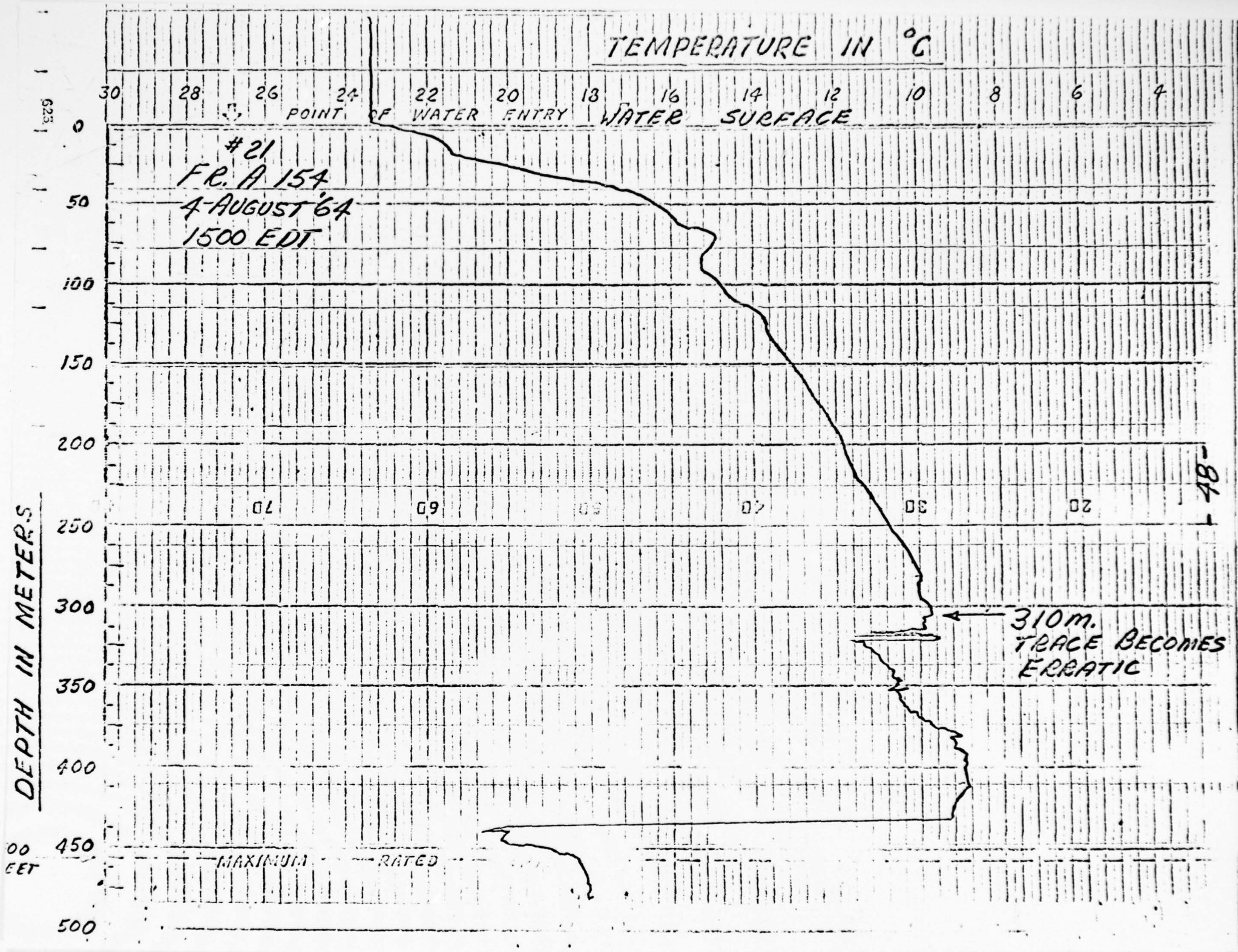
The General Motors BT units were manually launched. A support stand supplied by the manufacturer to hold the shipboard cable canister was found to be too cumbersome for practical use. The canister was subsequently hand held by one person, while another person threw the BT and surface float overboard. In foul weather, as experienced on the final day of testing, the hand launching procedure became hazardous due to slippery footings and occasional flooding of the deck.

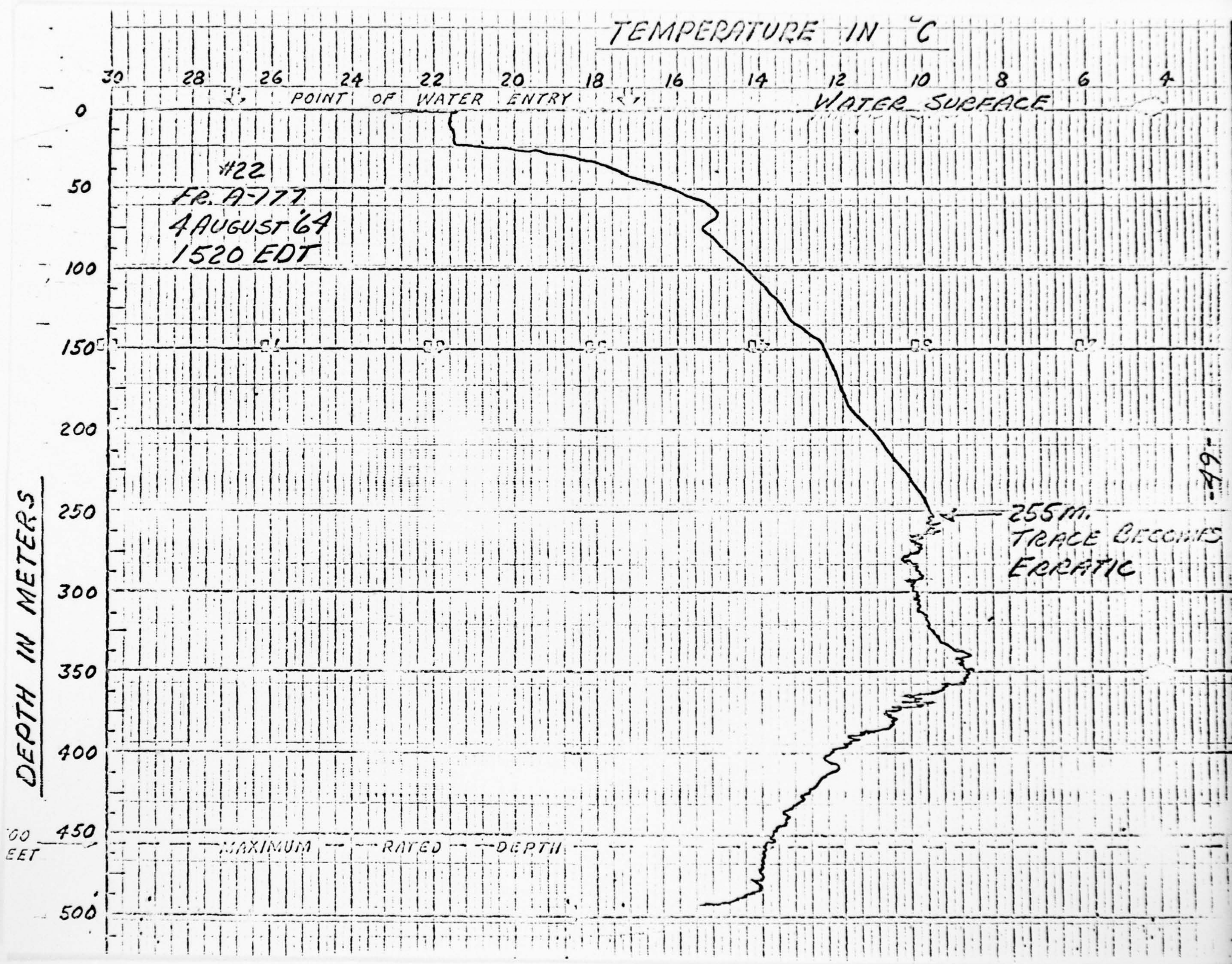
The results of high speed field testing are presented in Table IV and the sample expendable BT temperature profiles.

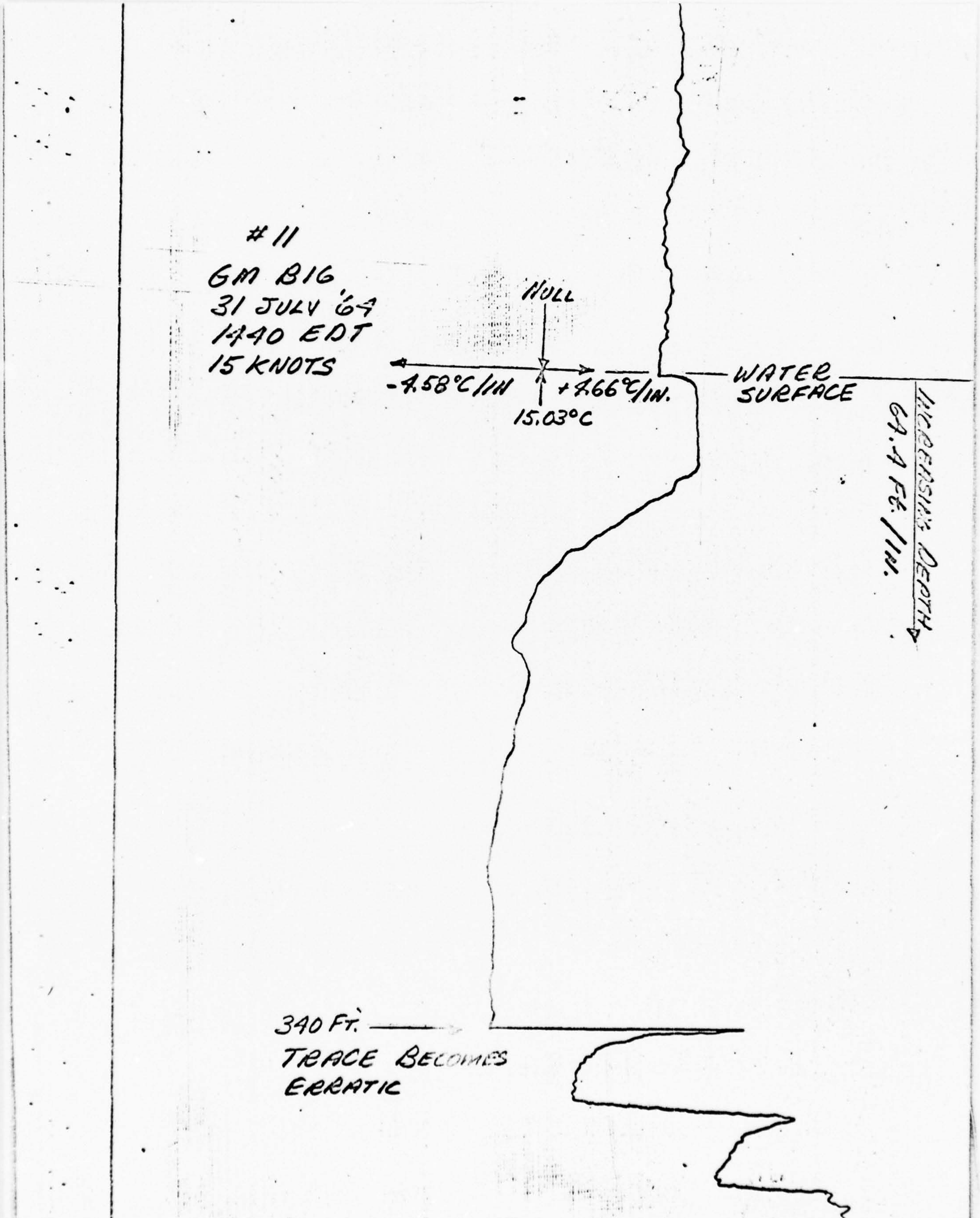
TABLE IV
EXPENDABLE BATHYTHERMOGRAPH EVALUATION
PHASE VI - FIELD TESTING

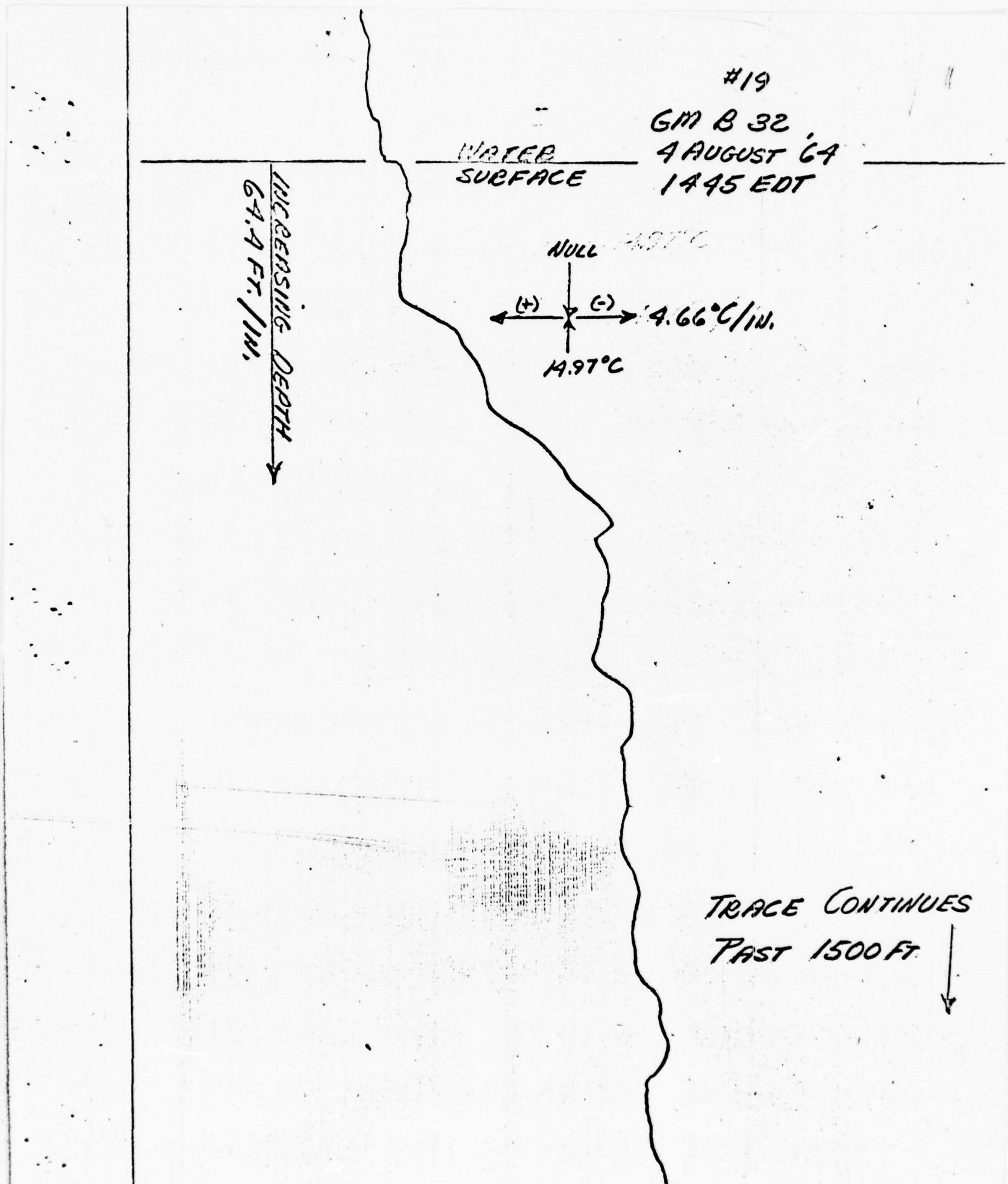
HIGH-SPEED TEST RESULTS

Test No.	XBT Mfgr.	Serial No.	Ship Speed (Knots)	Sea State	XBT Operating Depth (Ft)	Remarks
				30 July 1964		
1	Francis	A-31	25	NIL	1360	3-wire operation
2	Francis	A-24	"		1430	3-wire operation
3	Francis	A-25	"		75	2-wire operation
4	Francis	A-29	"		1340	3-wire operation
5	GM	B-13	"	Sea - (1-2') Swell (3-5') 7 sec. Period	0	Old Unit
6	GM	G-14	"		450	Old Unit - Float Removed
7	Francis	A-32	"		1150	2-wire operation
8	Francis	A-17	"		850	2-wire operation
9	Francis	A-173	"		440	2-wire operation
10	GM	B-18	"		385	Old Unit - Float Removed
				31 July 1964		
11	GM	B-18	15	NIL	340	Old Unit
				1 August 1964		
12	GM	B-15	15	NIL	210	Old Unit
13	GM	B-31	15		1500	New Unit
14	GM	B-35	15		0	New Unit
15	GM	A-2	15	Swell (1-2')	160	Old Unit
16	GM	A-1	8		1500	Old Unit
				4 August 1964		
17	GM	B-33	15	State 5	1050	New Unit
18	GM	B-34	18		97	New Unit
19	GM	B-32	18		1500	New Unit
20	GM	B-36	18	12-14' Swell 6-8' Sea	1500	New Unit
21	Francis	A-154	18		1020	2-wire operation
22	Francis	A-177	18		840	2-wire operation
23	Francis	A-150	18		410	2-wire operation
24	Francis	A-142	18		1310	2-wire operation


TEMPERATURE IN °C
30 28 26 24 22 20 18 16 14 12 10 8 6 4
POINT OF WATER ENTRY
WATER SURFACE
#21
FR. A 154
4-AUGUST '64
1500 EDT
310m.
TRACE BECOMES
ERRATIC
MAXIMUM RATED
DEPTH IN METERS
0 50 100 150 200 250 300 350 400 450 500


TEMPERATURE IN °C
30
28
26
24
22
20
18
16
14
12
10
8
6
4
POINT OF WATER ENTRY
WATER SURFACE
DEPTH IN METERS
0
50
100
150
200
250
300
350
400
450
500
#22
FR. A-777
4 AUGUST '64
1520 EDT
255 M.
TRACE BECOMES
ERRATIC
MAXIMUM RATED DEPTH


#11
GM BIG
31 JULY '64
1440 EDT
15 KNOTS
HULL
-4.58°C/IN
+4.66°C/IN.
15.03°C
WATER SURFACE
INCREASING DEPTH
64.4 Ft./IN.
340 FT.
TRACE BECOMES ERRATIC


#19
GM B 32
4 AUGUST '64
1445 EDT
WATER SURFACE
INCREASING DEPTH
64.4 FT./IN.
NULL
(+)
(-)
4.66°C/IN.
14.97°C
TRACE CONTINUES PAST 1500 FT.

TEST EQUIPMENT AND FACILITIES

Test equipment and facilities used in evaluation of the expendable bathythermograph concept are listed below in groups corresponding to the sources from which they were obtained.

A. General Motors Corporation

Item #	Quantity	Description
1	10	Type "A" Expendable BTs
2	20	Type "B" Expendable BTs
3	1	Oscillograph: Consolidated Electrodynamics Corp.: Type 5-124: 7" chart width: Type 7-341 Galvanometer (sensitivity 5.59 μa/in.): equipped with timing line accessory kit.
4	1	Digital D.C. Volt Meter: Digitec Corp.: Ser. #2362: 0-200 V.D.C.
5	1	Combined Power Supply and Bridge Network for Type "B" BTs: Mfg. by General Motors Corp.
6	1	BT Shipboard Cable Canister Support Stand: Mfg. by General Motors Corp.
7		Assorted Signal Cables, Leads, Etc.

B. Francis Associates Inc.

Item #	Quantity	Description
8	20	Expendable BT Units
9	1	BT Launch Tube Assembly: Mfg. by Francis Associates Inc.
10	1	Modified Strip Chart Recorder: Bristol Co.: power supply, non-linear slidewire, case, and bridge network to Francis Assoc. specifications.
11	1	Dummy BT Unit for Recorder Test: Mfg. by Francis Associates Inc.
12	2	Mylar Overlay Sheets with temperature and depth scales for reading BT record: Francis Associates Inc.

C. Basic Devices Inc.

Item #	Quantity	Description
13	10	BT Units
14	5	Modified BT Units (modified case, cable, cable canister, temperature sensing circuit, and pressure sensing circuit)

Item #	Quantity	Description
D. U. S. Naval Oceanographic Office		
15	1	Precision Guarded Resistance Measuring Facility: Leeds and Northrup Co.: Catalog #4232-A1: Range - 0 to 100k ohms in 0.1 ohm increments: Accuracy - 0.01% of reading.
16	1	Integrating Digital Volt Meter: Dymec Co.: Model 2401A: calibrated and repeatable to 2 v or 0.1v scale.
17	1	"X" - "Y" Recorder: Mosely Model "2D": Accuracy - 0.2% of full scale.
18	1	Storage Oscilloscope: Tektronix Type 564 with Type 3A1 Dual Trace Amplifier and Type 2B67 Time Base.
19	1	Oscilloscope: Tektronix Type 545A
20	1	Amplifier: KinTel Model 111BF
21	1	Oscilloscope Camera: Hewlett-Packard - Polaroid Model 196B.
22	1	Solid State Digital Counter: Hewlett-Packard Model 5532A: 1 MC Time Base: Accuracy - 2 parts in 10^6: Period Measurement Accuracy - 1 sec $\pm$ Time Base Accuracy.
23	1	X10 Attenuation Probe for Tektronix Type 564 Oscilloscope: Tektronics Inc.
24	10	Precision Fixed Resistances - Assorted Valves: General Radio Co.: Accuracy - 0.05% of stated resistance.
25	1	Decade Resistor: General Radio Co.: 0-100k ohm in 1 ohm increments: Accuracy $\pm$ 0.05% of reading.
26	1	Solenoid Actuated Two Way Valve: Barksdale Valves, Inc.: Model 141.
27	1	Regulated Temperature Bath: American Instrument Co. Model 4-8605: Bath Uniformity - $\pm$ 0.02°C (for 15 minute test periods: by measurement)
28	1	Pyrex Jar - 15" diameter by 15" height
29	1	Pressure Test Vessel: Built to Evaluation Branch Specifications: 10,000 psi capability - used to 650 psi during BT evaluation: pressure monitored to $\pm$5 psi in 650 psi range.

Item #	Quantity	Description
30	1	Hydrophone: U.S. Sonics Corp. Model SB-154C.
31	2	Mercury-Glass Thermometers: Fisher Scientific Co.: -1 to 51°C in 0.1°C increments: Total Immersion: calibrated and readable to ± 0.025°C: Serial Nos. 1C3292 and 1C3382
32	1	Laboratory Standard Cell: Eppley Co.: Unsaturated Laboratory Standard: 1.01929 volts: Accuracy - ± 0.005%
33	1	Frequency Changer: Sorensen Model FCR 100: Used as Frequency Regulation Source: Stability - 60cps ±0.05cps for 10 minutes, by test (input frequency varied from 55-66 cps, input voltage varied from 105 to 125 V.A.C.)
34	1	A.C. Voltage Regulator: Sorensen Model 30008: 117 volts ±0.1 volt
35	1	Telemetering Thermistor Thermometer: H.R.B. Singer Co. Model U2104B: calibrated and repeatable to ±0.02°C
36		Oceanographic Research Vessel: USNS GILLISS (AGOR-4)

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Item #	Quantity	Description
37		Undersea Weapons Test Tank: 100 feet deep, 50 feet diameter, movable submerged platform which can be set at any tank depth to within ± one-half inch: fresh water filled.

F. Fabricated Equipment

Item #	Quantity	Description
38	1	Supporting Frame - Fabricated of 1/2" mesh hardware cloth to maintain position of BT units in regulated temperature bath
39	1	Thermal Response Test Stand-Nozzle and Support Stand to produce 25fps flow past Francis BT units - Solenoid actuated valve
40	1	BT Release Mechanisms and Control Unit - Solenoid actuated release mechanisms with counter triggering switches for use in sink rate testing
41	1	Support Stand - Frame constructed for BT units and reference temperature sensor - all

Item #	Quantity	Description
		thermistors located within one-half inch of reference sensor - used in determination of effect of pressure on thermistors
42	3	3 pole 5 position switch boxes - used to select BT units for temperature testing

APPENDIX I

GENERAL PERFORMANCE SPECIFICATIONS FOR A SHIPBOARD EXPENDABLE BATHYTHERMOGRAPH

General

A need exists in the oceanographic community for the design and development of a relatively inexpensive expendable bathythermograph which can be launched from ships while underway. Such a device could be used effectively in the ASWEPS Program by both fleet tactical ships, as well as by "ships of opportunity", in the ASWEPS Synoptic Network. The system, as envisioned, could have the capability of telemetering temperature as a continuous function of depth to 1,500 feet at ship speeds to 20 knots and sea states up to 5 (8-13 ft.). The sensor package should be easily launched, and its accuracy should be such that the data collected will serve as a useful input to ASWEPS. Associated shipboard electronics necessary to receive and record the data should be simple and economical to manufacture and should not degrade sensor accuracy. In addition, the system should be designed for compatibility with existing ships' facilities and space available, for installation with minor modifications only, and for operation without interference with the ships' normal routine.

Performance Specifications

The expendable bathythermograph should be designed to meet the following specifications:

Depth Range	1,500 feet at 20 knots
Depth Accuracy	0 to 1,500 feet, ±2% or 15 ft., whichever is greater
Temperature Range	0° to 30°C
Temperature Accuracy	± 0.2°C
Time Constant	Not greater than 0.15 sec.

It is expected that the system will ultimately be composed of three major elements: the sensor package and trailing wire assembly, the deck electronics and recording assembly, and the launching equipment.

Sensor Package and Wire Assembly

1. Since the BT will be launched from ships at speeds up to 20 knots, it is considered imperative that the sink rate be high (15 to 20 fps) in order to limit the length of wire which must be trailed from the ship.

2. Size of the sensor package should permit easy handling by one man.

3. Design of the sensor package and weight distribution considerations should aim at providing a stable attitude (to prevent tumbling) during descent.

4. Placement in the housing and design of the sensor(s) should be such as to minimize self-heating effects and to assure sufficient flushing action to record a free environment.

5. Wire bales in the sensor package and aboard ship shall be designed to offer low pull-out friction.

APPENDIX II

TEST PLAN
EXPENDABLE BATHYTHERMOGRAPH (BT)

The objective of this test plan is to determine the overall operational capability of the Expendable Bathythermograph. Laboratory and field tests have been designed to determine its accuracy, repeatability, and reliability. Test results shall be compared with published specifications. Tests shall consist of the following:

1. Temperature
2. Thermal Response
3. Pressure Effects on Thermistors
4. Impact Shock
5. Sink Rate
6. Field Tests

Facilities to be used:

NAVOCEANO Instrumentation Division Laboratory.
Naval Ordnance Laboratory Test Tower.
Ship capable of 30 knots.

Equipment to be used:

Two AMINCO portable temperature baths, range -29° to 71°C, accuracy ±0.1°C.
One Hydrophone with amplifier.
Mercury in glass standard thermometers, range -1° to 40°C with 0.1°C scale units.
One digital voltmeter.
One digital ohmmeter.
One recorder (Brush Mark 280 or equivalent).
One hydrostatic pressure tank with electrical lead-in for tests to 650 psig.
One electronic counter.
One DC power supply.
Fabricated switch boxes, BT rack and release mechanism.
Miscellaneous hardware.

1. Absolute Temperature:

A test for system accuracy including expendable unit, recorder, and interconnecting cable will be made.

Purpose: To determine system accuracy and repeatability over the specified temperature range.

Synopsis: Expendable units to be tested shall be totally immersed in the Aminco controlled temperature bath. Connection to the recorder shall be made via the interconnecting cable.

Each unit shall be subjected to three temperature cycles over the range from 0^{o} to $30^{o}C$. Temperature readings shall be taken at increments of $5^{o}C$ with three readings at increasing temperature and three at decreasing temperature. Readings shall be recorded for comparison with specifications.

a. Equipment:

Aminco Bath
0 to $40^{o}C$ thermometer 0.1^{o}C graduations
Digital DC voltmeter
Switch boxes
BT rack
Precision DC power supply

b. Procedure - (*BTs are to be numbered 1 to 10*)

Five BTs of a single manufacturer are to be in bath at the same time. If room in bath is available, additional lots are to be placed in the bath at the same time. BTs are to be separated by rack to allow free circulation of coolant. Thermometer is to be fully immersed and to be read to .025^{o}C. Switching from one unit to another is to be accomplished by a switch box and readings are to be taken as closely together as possible. Depending upon the design of the BT readout will be either volts or resistance as indicated by current and voltage. Bath temperature at beginning and end of each lot of 5 BTs is to be recorded. Readings of BT output at approximately $5^{o}C$ intervals from 0 to $30^{o}C$ are to be recorded. A total of six runs are to be made with each lot (or lots) three at increasing and three at decreasing temperatures in alternating cycles.

The readings of output will be as indicated by the recording or indicating equipment as supplied by or recommended by the manufacturer. In the event that this is not possible, readings will be of voltage or resistance taken after all expendable wiring and circuitry.

The BT supporting rack may be fabricated of heavy (1/2" squares) hardware cloth with appropriate openings cut in it to support the BTs in a natural vertical position, spaced so as to insure free circulation.

The switch box will be constructed so as to allow convenient switching of signal from, and if needed, supply voltage to the entire expendable unit, for each of the lot of 5 expendable units.

c. Data Presentation:

The final data will be displayed as follows:

Sheet # ______

(Title) EXPENDABLE BT (MFGR.) Taken By (Name)

Phase: 1 ABSOLUTE TEMPERATURE Date ( )

BT# / Bath Temp.	1	2	3	4	5		
0	(Temperature Error)						
5°C							
etc.							

The data will then be reduced to yield (in C°)

a. Maximum error
b. Average error

The reduced data summary will be tabulated as follows:

Sheet # ______

(Title) EXPENDABLE BT Calc. By (Name)

Phase: 1 SUMMARY OF ABSOLUTE TEMPERATURE TEST Date ( )

Mfgr. / Temp. Error	G. M.	Francis	Etc.				
Maximum							
Average							

In addition to the above numerical data any personal observations made during the test relative to stability, simplicity, reliability and/or any other factor of possible use in the evaluation of any of the units tested should be noted on a separate sheet of paper including the date and name of observer and should be indexed to the particular data to which it applies and is to be attached to the final data sheet.

If any of the data indicates a consistent error of greater than ± 0.2°C, the test is to be rerun with the supplied or recommended recording equipment replaced by the precision instruments as deemed necessary by the experimenter to accurately evaluate the expendable portions precision.

2. Thermal Response:

Purpose: To determine the temperature time constant of the thermistors.

Synopsis: Each unit shall be placed in a room temperature bath, allowed to reach thermal stability, and then plunged into 30°C bath. A plot of temperature versus time shall be made to establish a response curve. The thermistors shall reach 63 percent of 30°C within 0.15 second (time constant).

a. Equipment

Aminco bath
Recorder (Brush Mark 280 or equivalent)
Precision DC power supply
0 - 40°C thermometer .1°C div. (R&D)

b. Procedure:

Each BT of each manufacturer will be allowed to stabilize at room temperature. The unit under test will be wetted in a room temperature bath, removed, and 30 seconds later plunged into the aminco bath at approximately 30°C. The readout shall be via the recording equipment supplied or recommended by the manufacturer. If this is not possible, readout will be via the Brush recorder. The time constant shall be taken to be the time necessary to respond to 63% of the temperature differential between the air temperature and the bath temperature. Care should be taken to insure that the recording equipment or necessary amplifiers do not degrade the time constant.

The data shall be recorded as follows:

Sheet # ______

(Title) EXPENDABLE BT				Taken By ( )		
Phase: 2		THERMAL RESPONSE			Date ( )	

BT# / Mfgr.	1	2	3	4	5	6
G. M.		(Time constant in seconds)				
Francis						
Etc.						

If any of the data indicates a time constant of over 0.15 sec., additional experimentation will be necessary to determine whether or not this is contributed to by the recording equipment. To check this, the supplied or recommended recording devices will be replaced by the Brush equipment and the test will be rerun.

In addition, any personal observations as outlined in the "absolute temperature" section will be handled according to the procedures stated therein.

3. Pressure Effects:

Purpose: To determine the effects of pressure on temperature.

Synopsis: One each of the expendable portion of a particular manufacturer's BT shall be subjected to this test. Each unit shall be placed in a pressure tank at a pressure of 650 psi and temperatures monitored. After the temperature has stabilized, pressure shall be relieved in increments of 100 psi. Monitor readout unit for temperature to determine any changes.

a. Equipment:

Pressure bomb
Thermometer calibrating tank

b. Procedure:

One BT of each manufacturer is to be placed in the pressure bomb individually. Pressure is to be raised to 650 psi and maintained. Tank temperature is to be maintained at 20°C for 1 hour at which time

BT sensor output is to be recorded. If indicated temperature is more than $\pm 1^{\circ}C$ from bath temperature, the pressure shall be relieved in 100 psi increments and a temperature stabilization time of 1 hour shall be allowed before indicated temperature is recorded. The signal wiring will utilize waterproof connectors.

The data is to be recorded as follows:

Sheet # ______

(Title) EXPENDABLE BT Taken By ( )

Phase: 3 PRESSURE EFFECTS Date ( )

Mfgr. / Press.	G. M.	Francis	Etc.		
650 psi					
error					
550 psi					
error					
Etc.					

In addition, any personal observations as outlined in the "absolute temperature" section will be handled according to the procedures stated therein.

4. Impact Shock:

Purpose: To determine the effect on the operation when simulating the dropping of the expendable unit over the side of a ship.

Synopsis: One each of the expendable portion of a particular manufacturer's unit shall be subjected to this test. The test tower at Naval Ordnance Laboratory shall be used for this test.

Each unit shall be dropped in free fall from a height of 30 feet. Three drops shall be made. After test, the units shall be inspected visually for effects of impact and shall be retested for compliance with tests 1 and 2. If failure occurs in the initial unit selected, a retest shall be made on another unit.

a. Equipment:

NOL test tank
Miscellaneous hardware

b. Procedure:

One each, of the expendable portion, of each manufacturer's BT is to be dropped from a 30 foot height into the water. The unit shall be tethered to prevent complete fall to tank bottom (and causing damage to the thermistor). Three drops per unit are to be made and variety of launch angle and attitude should be performed. Care is to be exercised in handling of the units such that no damage should result other than that as a possible result of the drop testing.

Visual inspection and observation, and retesting in accordance with steps 1 and 2 shall be performed.

c. Data Presentation:

The data of this section will be qualitative, and as such, is to be handled in accordance with the procedure as outlined in step 1 (i.e., absolute temperature section).

The retest data is to be presented as described in the respective test step (1 and 2).

5. <u>Sink Rate:</u>

Purpose: To determine the rate of descent and depth accuracy of the expendable BT.

Synopsis: Two expendable BTs of a particular manufacturer shall be subjected to this test. The test tower at Naval Ordnance Laboratory shall be used for this test.

Each BT shall be dropped into the water and allowed to sink the full depth of the tower (100 feet). An electronic timer shall be switched on at the same time the BT is dropped. As the unit sinks, readings of time shall be taken when the unit strikes the platform. A total of five drops shall be made with each unit and the times of descent recorded. The times shall be averaged to give the sink rate and accuracy. The expendable wire is then to be removed and the test rerun.

a. Equipment:

NOL test tank
Electronic Counter
Hydrophone and amplifier
Release mechanism and hardware

b. Procedure:

Each BT is to be released at the water surface by the release mechanism. This, in turn, triggers the counter which counts its internal crystal frequency. Upon impact with the bottom platform, the counter is switched off by the hydrophone. The platform is then raised to a new depth (25, 50, 75, and 100 foot depths) and the test rerun.

Two units, (of each manufacturer) will be dropped five times each, and the drop times averaged. This procedure is then to be repeated with all expendable wire removed from the unit.

Observation will be made of the lateral distance each BT strays from the drop point.

Wire will not be deployed during this test.

c. Data Presentation:

The final data will be presented as follows:

Sheet # ______

(Title) EXPENDABLE BT Taken By ( )

Phase: 5 SINK RATE Date ( )

Mfgr. / Test Depth	G. M.	Francis	Etc.		
100	(Drop times)				
75					
50					
25					
100	(Less wire)				
75					
50					
25					

The data will then be reduced to yield

a. Average sink rate (ft/sec)
b. Maximum deviation from average sink rate (%)
c. Maximum variation in sink rate (%) for both wired and wireless conditions
d. Difference of average sink rates for wired and wireless conditions (%)

The reduced data summary will be tabulated as follows:

Sheet # ______

(Title) EXPENDABLE BT Calc. By ( )

Phase: 5 SUMMARY OF SINK RATE TEST Date ( )

Mfgr. / Sink Rate	G. M.	Francis	Etc.			
Average						
Max. Dev.						
Max. Var.						
Difference						

All significant personal observations are to be recorded as outlined in "absolute temperature section".

6. Field Tests:

Purpose: To determine the operational capability and accuracy of data of expendable BTs at ship's speeds up to 30 knots.

Synopsis: Expendable units of a particular manufacturer shall be dropped from a ship and a record made of temperature and depth.

Expendable units shall be dropped from a ship operating at speeds of 10, 15, 20, 25, and 30 knots and records evaluated to determine the overall operation of the BTs.

a. Equipment

Ship capable of 30 knots
Electronic BT
Nansen cast (1500' @ 100' intervals)
Necessary deck electronics

b. Procedure:

Two each, of a manufacturer's BT, shall be dropped from the ship at a fixed station. As a reference, a Nansen cast and an electronic BT profile are to be taken at the same time.

The remaining units are to be expended at speeds up to 30 knots and if possible, under varying sea states and in areas of sharp thermoclines.

c. Data Presentation:

The resulting Bathythermograms are to be compared and good agreement should be found between the Nansen cast data and the electronic BT. Assuming this to be the case, deviations from this standard curve as recorded by the expendable units can be noted and the unit's performance can be evaluated.

Wire insulation breakdown will most probably be evidenced by a sudden erratic recorder operation and should be noted in the data.

Such intangible factors, as ease of operation, handling and launching problems, equipment difficulties, etc., are to be recorded.

The data will be reduced to yield

a. Maximum deviation of the expendable BT from the "standard" curve in °C at a given depth.
b. Insulation breakdowns.
c. Percent of "valid" drops.

REFERENCES

Proposal for an Expendable Bathythermograph System: Packard Electric Division of General Motors, Warren, Ohio.

Technical Description - Expendable Bathythermograph System: Proposal R-271B, January 1964: Francis Associates, Inc., Marion, Mass.

Depth Error Analysis - Expendable Bathythermograph System, Section 3: Francis Associates, Inc., Marion, Mass.