NASA CR-54960

FACILITY FORM 602

N66 24696 (ACCESSION NUMBER)	(THRU)
65 (PAGES)	1 (CODE)
CR-54960 (NASA CR OR TMX OR AD NUMBER)	14 (CATEGORY)

EIGHTH QUARTERLY REPORT

PRESSURE MEASURING SYSTEMS FOR CLOSED CYCLE LIQUID METAL FACILITIES

Anthony J. Cassano

GPO PRICE $ ________

CFSTI PRICE(S) $ ________

Hard copy (HC) 3.00

Microfiche (MF) .75

ff 653 July 65

PREPARED FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTRACT NAS 3-4170

April 8, 1966

Consolidated Controls Corporation

Bethel, Connecticut

A SUBSIDIARY OF CONDEC CORPORATION

NOTICE

Requests for copies of this report should be referred to:

National Aeronautics and Space Administration
Scientific and Technical Information Facility
P. O. Box 33
College Park, Md., 20740

NASA CR-54960
CCC-546

EIGHTH QUARTERLY REPORT
December 1, 1965--February 28, 1966

PRESSURE MEASURING SYSTEMS FOR CLOSED CYCLE LIQUID METAL FACILITIES

PREPARED FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTRACT NAS 3-4170

April 8, 1966

Technical Management
NASA - Lewis Research Center
Nuclear Power Technology Branch
R. N. Weltmann

Prepared by:

Anthony J Cassano

Anthony J. Cassano
Research Physicist

Approved:

R. E. Engdahl

R. E. Engdahl
Manager, Advanced
Research & Development

CONSOLIDATED CONTROLS CORPORATION
Bethel, Connecticut

FOREWORD

The major contributors to this development program are Mr. R. Engdahl, Mr.Anthony Cassano, Mr. George Garrity, Mr. David Mends and Mr. Philip Tubman.

ABSTRACT

24696

Continuing development of a thermionic diode pressure transducer for liquid metal applications is described. Experimental results on the latest transducer test models indicate that fabrication changes introduced in the thermionic diode sensor have increased the expected operating life well beyond the 1000 hour level. The final designs of the 80 psia and ± 5 psid transducers are well along. A double housing is planned; an inner Nb-1Zr main housing to establish a low vapor pressure environment for successful operation of the thermionic sensor, and an outer L-605 alloy shell to enable the transducer to be used on a liquid metal test loop operating in air. Tests on the breadboard model of the transducer electrical signal conditioning system indicated that the various control loops are operating properly. It remains to connect the breadboard to a transducer test model to evaluate the integrated operation of the conditioning system.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF TABLES

1.0 Introduction

The objective of this program is to develop pressure transducers which can be used in advanced Rankine cycle space power systems using liquid metals such as mercury, sodium, potassium and other alkali metals as working and heat transfer media at elevated temperatures. Accurate pressure measurements in the high temperature liquid, vapor, and two phase streams are required for research, design and control purposes. In addition, space flight requires lightweight systems capable of enduring long periods of unattended operation.

Liquid metal pressure measurements at elevated temperatures pose many design problems demanding the best from available materials. To establish a firm design base for the transducer equipment, four diaphragm materials and two transducer systems were chosen for evaluation. The selected transducer system using a thermionic diode sensor is being developed for use as either ground or flight hardware for measuring absolute and differential pressures. The absolute and differential pressure instruments are being developed for full scale ranges of 80 psia and ±5 psid respectively.

2.0 Summary

Transducer test unit T-6 was built using the FS-85 pressure capsule taken from test unit T-5. Changes made in the thermionic sensor, including the removal of the secondary reference collector and changing the emitter thermocouple material and emitter activation procedures, were intended to extend the 850 hour life demonstrated by the testing performed on T-5.

Transducer test unit T-7 was built using the C-129Y pressure capsule taken from test unit T-4, which completed 1500 hours of continuous operation. The thermionic sensor of T-7 included a secondary reference collector to check its effect on the operating life.

Some erratic test data obtained with T-5 indicated the possible existance of errors due to temperature instabilities in the test chamber. As a check, a series of tests were run on the temperature characteristics of the Vacuum Test Facility and the thermionic emitters. Test unit T-4 was used for these tests. Results indicated that the methods presently in use for determining chamber and emitter temperatures yield accurate results.

During the report period, about 1375 and 1125 hours of operation were accumulated on T-6 and T-7, respectively. Two series of pressure-output tests were run. The first series used a constant sensor supply voltage at zero pressure for all test temperatures. The second series used a constant sum-of-the-currents value at zero pressure for all test temperatures. Zero shift effects observed during the first test series were greatly decreased in the second test series. The changes introduced in the fabrication of the thermionic sensors of T-6 and T-7 appeared to solve the emission problems encountered in the testing of T-4 and T-5. Data accumulated thus far has not indicated any effect of the secondary reference collector on operating life.

Design work on the final absolute and differential transducer configurations was started. Use of a double housing is planned. An inner housing of Nb-1Zr provides the low vapor pressure environment needed for the thermionic sensor while an outer shell of L-605 alloy allows the transducer to operate in air at 1800°F.

The metal-ceramic test seals scheduled for potassium compatibility testing were completed, installed in their test assemblies and shipped for potassium charging. Compatibility testing is scheduled to start about the end of March.

Test work was continued on the transducer electrical signal conditioning system breadboard. A new supply transformer was wound and installed on the breadboard. Using simulated input signals, checks on the various control loops were successfully completed. The breadboard was connected to test transducer T-7 for further testing.

3.0 Thermionic Diode Pressure Transducer Test Units

At the conclusion of the previous report period (Reference 1), transducer test units T-4 and T-5 had been in continuous operation at temperatures up to 1800°F for about 1500 and 850 hours respectively. At that time, some loss in emission was observed from the emitters used in the reference circuit. To a lesser extent, the same effect was noticed in the active emitter circuits. To remedy the emission loss and extend the thermionic diode sensor life beyond the 1000-1500 hour level, three specific areas were chosen for investigation. One was the braze joint holding the secondary reference collector in the Lucalox section of the sensor. During operation, the braze material may have reacted with the emitter. The second was the platinum thermocouple used to monitor the emitter temperature. The emission could have been degraded by platinum migration over the emitter surfaces. Lastly, the loss in emission may have been due to an overextended activation procedure which resulted in excessive loss of impregnant material from the emitters.

To investigate the problem areas mentioned above, T-5 was disassembled and the FS-85 pressure capsule was fitted with a new thermionic diode sensor to form a new test unit, T-6. The thermionic diode sensor had the following features.

1. The sensor did not include the secondary reference collector.
2. The Pt/Pt-13 Rh thermocouple was replaced by a W-5 Re/W-26 Re thermocouple. This thermocouple was spot-welded to the emitter housing.
3. The emitters were pre-activated in vacuum (about 10^{-6} torr) at 2280°F for 25 minutes before assembling the sensor. In the Vacuum Test Facility, another 20 minute pre-activation period at 2280°F was completed. Current was drawn from the emitters during the second pre-activation procedure.
4. The Nb-1Zr "bolts" used to hold down the emitter housing to the Lucalox base were rhenium-plated. The plating was done to avoid any possible reaction between the columbium and the Lucalox.

Before test unit T-4 was disassembled, several tests were performed to determine the temperature characteristics of the Vacuum Test Facility and the thermionic emitters. These tests will be detailed in Section 3.1. Following the temperature tests, T-4 was disassembled and the C-129Y pressure capsule was fitted with a new thermionic diode sensor to form a new test unit, T-7. The sensor was identical to the sensor prepared for T-6 except that a secondary reference collector was included. Comparison of data collected on T-6 and T-7 should indicate whether the secondary reference collector has any detrimental effects on sensor operating life. If testing indicates that the secondary reference collector should not be used, the W-5 Re/W-26 Re thermocouple could be used in the final design to indicate and control the emitter temperature.

3.1 Temperature Test Results

During the previous report period, experimental data gathered on T-5 yielded erratic results. Some of these data indicated the possible existance of errors due to temperature instabilities in the test chamber and corresponding questionable values of assumed chamber and emitter temperatures. As a check, a series of tests were run to determine the temperature characteristics of the Vacuum Test Facility and the thermionic emitters. Test unit T-4 was used for these tests.

The test chamber and thermionic emitter temperatures were continuously monitored and displayed on a recorder instrument. The chromel/alumel thermocouple inserted into the argon pressurization tubing near the pressure capsule was used to indicate ambient temperature. The platinum thermocouple spot-welded to the emitter housing indicated the temperature of the emitter. The tests were run at test chamber temperatures of 1800, 1600, 1400, 1200 and 1000°F. The emitter temperature for the tests was 2100°F. The test results may be summarized as follows.

1. A change in either the test chamber or emitter temperature was reflected in the other. As the test chamber temperature was varied, the emitter temperature changed in the same direction, and stabilized in about the same time.

2. There was no hunting effect. Both temperature changes were gradual with no observable undershoot or overshoot.

3. The introduction of argon to pressurize the capsule resulted in a higher thermocouple output than was obtained under zero pressure (vacuum) conditions. The magnitude of this effect was independent of argon pressure and was most noticeable at the lower temperatures (1000, 1200 and 1400°F). At 1600 and 1800°F, the change in the thermocouple output was minimized. It appeared that at the lower temperatures, heat conduction through the argon was a more efficient transfer mechanism than radiation in vacuum. For the higher temperatures, radiation heat transfer was close to the conduction mechanism through the argon.

4. The recorder data verified the accuracy of the methods previously used to monitor the chamber and emitter temperatures. These procedures involved spot-checking the temperatures periodically with a thermocouple read-out bridge and allowing about one hour for a stable temperature distribution to be established.

3.2 Pressure - Output Test Results

During the report period, experimental work concentrated on test transducers T-6 (FS-85 pressure capsule) and T-7 (C-129Y pressure capsule) which accumulated operating times of about 1375 and 1125 hours, respectively. The main purpose of the test series was to determine whether changes made in the fabrication of the thermionic sensors of T-6 and T-7 would increase the operation life beyond the 1500 and 850 hour times shown by test transducers T-4 (C-129Y pressure capsule) and T-5 (FS-85 pressure capsule). The details of the fabrication changes were presented in Section 3.0.

Two complete sets of pressure-output tests were run on both T-6 and T-7. The tests consisted of three pressure cycles at 1800, 1600, 1400, 1200, 1000, 1200, 1400, 1600, and 1800°F. Space-charge data taken before and after the temperature runs were used to indicate the active and reference collector distances and any emitter poisoning that might be present. The procedures for obtaining and interpreting the space-charge data are outlined in Reference 1, page 9. For the first tests on both T-6 and T-7, the supply voltage for zero pressure was 10 volts for all test temperatures. The use of a constant zero-pressure supply voltage for all temperatures, coupled with any shifts in the pressure capsule (active collector) with temperature, resulted in different sum-of-the-currents ($i_a + i_r$) values at each temperature. Complete sets of pressure-output current ($i_a - i_r$) data from T-6 and T-7 are presented in Figures 1 through 8. Figures 1 through 4 relate to T-6 and Figures 5 through 8 relate to T-7. For both transducers, the data are presented in the following sequence; initial space-charge data, pressure-output data for decreasing temperatures, pressure-output data for increasing temperatures and final space-charge data.

From the initial space-charge data shown in Figures 1 and 5, an operating voltage of about 10 volts was chosen for T-6 and T-7. This voltage resulted in no apparent poisoning effect in either sensor. To obtain about 0.001 inch pressure capsule deflection, full scale pressures of 50 inches of mercury and 60 psia were chosen for T-6 and T-7, respectively.

Table 1 presents the various current parameters with 10 volts applied to the sensor at zero pressure. The data of Table 1 indicate that the major portion of the zero shift with temperature in the output current ($i_a - i_r$) is due to shifts in the active collector distance probably related to thermal expansion effects (Reference 1, page 12). As the temperature decreased, the pressure capsule contracted and the active collector distance decreased, resulting in an increase in i_a. The effect is more pronounced in T-6 than in T-7, shown by comparing the shifts with temperature of the data of Figures 2 and 3 (T-6) with the shifts with temperature of the data of Figures 6 and 7 (T-7).

TABLE 1

ZERO PRESSURE TEST PARAMETERS; CONSTANT APPLIED VOLTAGE, 10 VOLTS

Test Temp °F	T-6		T-7	
	$i_a + i_r$ ma	$i_a - i_r$ ma	$i_a + i_r$ ma	$i_a - i_r$ ma
1800	89.4	24.6	74.0	21.7
1600	95.9	31.8	77.8	24.7
1400	107.1	43.0	79.4	27.5
1200	126.7	58.4	82.0	28.9
1000	146.7	74.6	85.4	30.6
1200	138.7	65.2	83.2	26.7
1400	122.6	51.3	80.8	25.4
1600	110.9	41.3	75.8	23.0
1800	104.1	36.3	67.9	21.1

Figures 1 and 4, the two sets of space-charge data on T-6, indicate that the active collector distance decreased from a little under 0.004 inch prior to the temperature tests to about 0.0035 inch following the temperature tests. Space-charge runs taken about two weeks later showed that the active collector distance had decreased still further to about 0.0032 inch. At that time, T-6 was removed from the test chamber to adjust the active collector distance to a value closer to that of the reference collector (about 0.005 inch). The thermionic sensor was shimmed to adjust the active collector distance and T-6 was re-installed in the test chamber.

The pressure-output tests were repeated on both T-6 and T-7. However, instead of using a constant zero-pressure voltage at all temperatures, a constant sum-of-the-currents ($i_a + i_r$) value was used for all temperatures. The thermal expansion effects mentioned above were minimized since any increases in current (especially i_a) were restricted by the constant ($i_a + i_r$) requirement. In addition, the tests were more representative of final transducer operation since the signal conditioning system operation is based on maintaining a constant ($i_a + i_r$) value.

Complete sets of pressure-output current ($i_a - i_r$) data from these second tests on T-6 and T-7 are presented in Figures 9 through 23. Figures 9 through 12 relate to T-6 and present the data in the following sequence; initial space-charge data, pressure-output data for decreasing temperatures, pressure-output data for increasing temperatures and final space-charge data. Figures 13 through 23 relate to T-7 and present the data in the following sequence; initial space-charge data, pressure-output-temperature data (Figures 14 through 22) and final space-charge data. Each temperature test on T-7 is presented separately since the data corresponding to each temperature test are not distinguishable when plotted on one format.

There was a marked improvement in zero shift indicated by comparing the pressure-output data of Figures 9 through 23 with those of Figures 1 through 8. Table 2 presents the various zero-pressure parameters using a constant sum-of-the-currents value (70 ma) for each temperature.

The improvement in zero shift is evident by comparing the $(i_a - i_r)$ values of Table 2 with those of Table 1. Using Table 1 data, the spreads in $(ia - i_r)$ values with temperature for T-6 and T-7 were 50.0 and 9.5 milliamperes, respectively. Using the sum-of-the-currents value as the reference parameter, the spreads in $(i_a - i_r)$ values with temperature, from Table 2, decreased to 20.6 and 2.4 milliamperes for T-6 and T-7, respectively.

The following general statements may be made from the test results.

TABLE 2

ZERO PRESSURE TEST PARAMETERS; CONSTANT SUM-OF-THE-CURRENTS, 70 ma

Test Temp °F	T-6		T-7	
	$i_a + i_r$ ma	$i_a - i_r$ ma	$i_a + i_r$ ma	$i_a - i_r$ ma
1800	70.0	17.2	70.0	24.3
1600	70.0	23.0	70.0	23.6
1400	70.0	28.1	70.0	24.7
1200	70.0	32.9	70.0	24.3
1000	70.0	37.8	70.0	23.2
1200	70.0	33.4	70.0	22.5
1400	70.0	28.3	70.0	24.3
1600	70.0	24.7	70.0	22.3
1800	70.0	23.5	70.0	23.6

1. T-7 (C-129Y) exhibited much less zero shift with temperature than T-6 (FS-85) during both test series (see Tables 1 and 2). From experimental results presented in Reference 2, it is expected that the W-25 Re material chosen for the final pressure capsule design will improve upon the performance of the C-129Y test unit T-7.

2. Hysteresis effects in the pressure-output data for both T-6 and T-7 were noticeable only at temperatures above 1400°F and, in some instances, 1600°F.

3. The hours of successful operation accumulated by T-6 and T-7 (1375 and 1125 hours, respectively) indicated that the fabrication changes used on these units may have solved the emission problems encountered in test units T-4 and T-5. Sufficient data was not obtained to determine the effect, if any, of the secondary reference collector on operating life.

4.0 Thermionic Diode Pressure Transducer Design

During the report period, work was started on the final housing designs for the 80 psia and ± 5 psid transducers. To enable the transducers to be tested on a loop operating in air, L-605 cobalt-based alloy received initial consideration as the material. Choice of this material permits the transducer loop testing to be done in either a 1600°F stainless steel loop or an 1800°F L-605 (or Haynes-25) loop.

Further investigation into L-605 revealed that this material has a vapor pressure between 10^{-5} and 10^{-6} torr at 1800°F. Installation of the thermionic diode sensor in a housing of L-605 would result in a poisoning of the thermionic emitters because of the relatively high vapor pressure. To avoid this poisoning, the designs for the absolute and differential pressure transducers were established around the use of a double housing concept; a main housing of Nb-1Zr surrounded by a shell of L-605 alloy. The thermionic sensor is installed in the low vapor pressure Nb-1Zr and the outer shell of L-605 allows the transducer to operate in air. The space between the Nb-1Zr and the L-605 will be evacuated to prevent oxidation damage to the Nb-1Zr.

Layout drawings of the transducer design were prepared to determine potential problem areas in the fabrication process. The various weld requirements were analyzed. All joints exposed to the liquid potassium environment will be electron-beam welded. The final closure welds associated with the thermionic sensor section may be either electron-beam or heliarc type. These joints will not be exposed to the liquid potassium environment and will maintain the vacuum requirements of the thermionic sensor. At present, the heliarc weld is preferred since this type of weld can be done at this company.

The use of a Nb-1Zr housing inside an L-605 outer shell required the use of a pressurization connection weldable to both Nb-1Zr and L-605. A transition piece has been designed to meet these requirements. A tapered slug of L-605 is forged into a tapered cavity in a piece of Nb-1Zr. The joint has been found to be sound. After final machining, the transition piece becomes a tube one end of which is Nb-1Zr, welded into the main housing and the other end is L-605, welded into the outer shell.

A preliminary design was established for the electrical connector set-up used to deliver power to the transducer and connect it to the signal conditioning equipment. The cable is of a swaged design about 2 feet long. The internal insulation is crushable ceramic and the outer cable shell is stainless steel tubing. The stainless tubing gives the cable a certain amount of flexibility needed for loop testing. The cable is internally pressurized with argon and a metal-ceramic seal is used at both ends. A weld connection is made to the transducer while a standard multi-pin connector at the cold end of the cable allows the use of a standard design cable to the signal conditioning equipment.

Final layout drawings of the absolute and differential pressure transducers, and their electrical connectors, will be presented in the next Quarterly Report.

5.0 Metal-Ceramic Seal Compatibility Program

The metal-ceramic test seals scheduled for potassium compatibility testing were completed. Five compatibility test assemblies, each containing four metal-ceramic test seals, were fabricated and shipped for potassium charging. Detailed sketches and information on the test seals and compatibility test assemblies were presented in Reference 1 (Table 31 and Figures 11 through 19).

The present estimate for the return of the assemblies and the start of the compatibility testing is the end of March. The procedure to be followed for the compatibility testing of the metal-ceramic seals is the same as that used for the compatibility testing of the four candidate pressure capsule materials (see Reference 3, page 18).

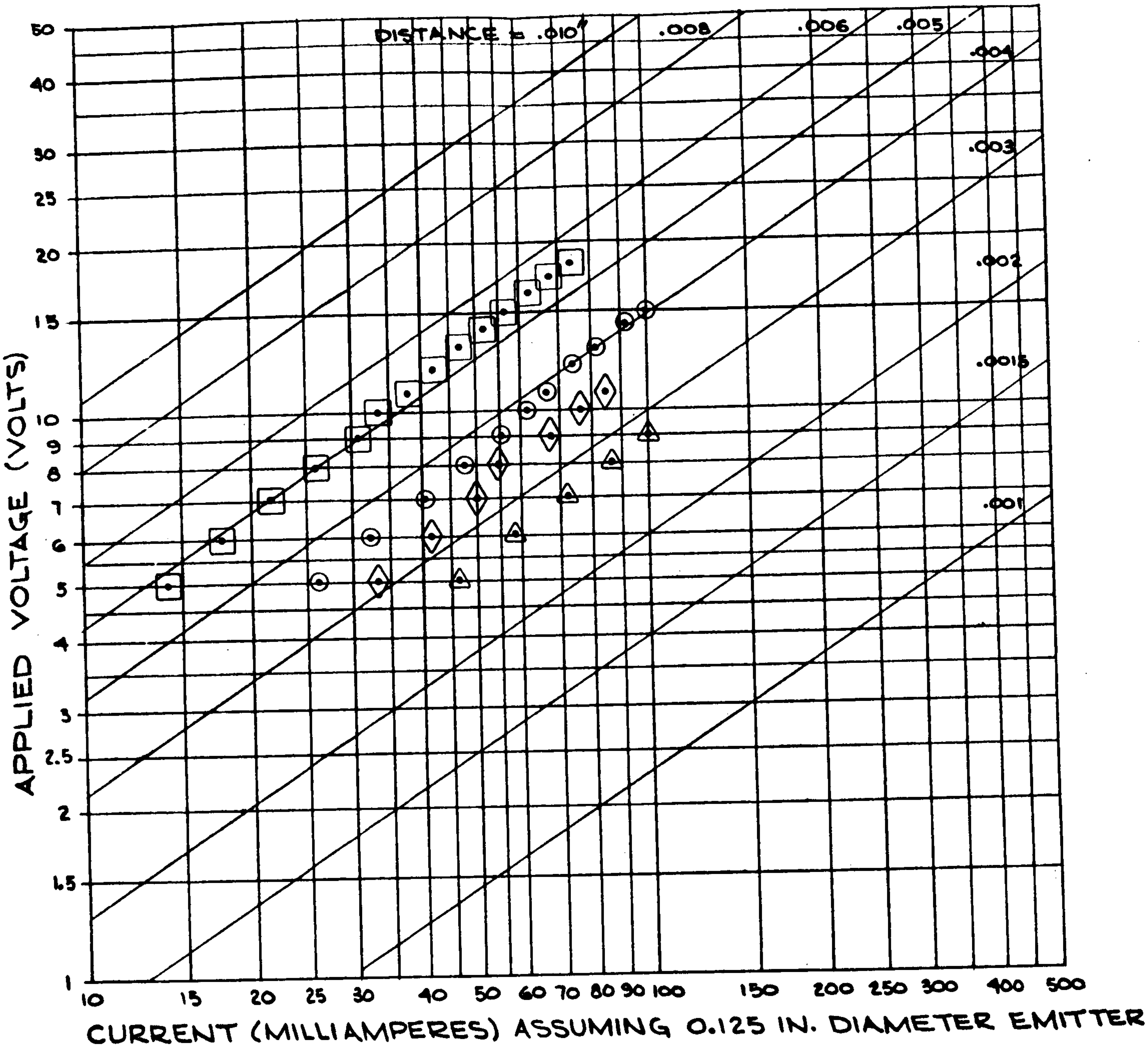
6.0 Transducer Signal Conditioning

During the report period, work on the electrical signal conditioning system concentrated on testing of the breadboard system. A block diagram of the electrical circuitry and a description of the various control loops of the system were presented in Reference 4.

During the initial testing, it was found that the supply voltage level in some of the control loops was low. A new supply transformer was designed, wound and installed in the breadboard. Using simulated input signals, the characteristics of the control loops were checked. Each circuit operated as planned.

At the conclusion of the report period, the breadboard was connected to transducer T-7 following the testing described in Section 3.2. Of prime interest will be data on the heater control loop relating the secondary reference collector parameters to the emitter temperature.

A complete summary of these data and a revised drawing of the electrical circuitry will be presented in the next Quarterly Report.



CAPSULE TEMP. 1800°F

EMITTER TEMP. 2100°F

——— CALCULATED FROM EQ.1, REF 5

⊡ REFERENCE COLLECTOR, ZERO PRESSURE

⊙ ACTIVE COLLECTOR, ZERO PRESSURE

◈ ACTIVE COLLECTOR, 25 IN. OF MERCURY

▲ ACTIVE COLLECTOR, 50 IN. OF MERCURY

FIGURE 1

INITIAL SPACE-CHARGE DATA, T-6 (FS-85)

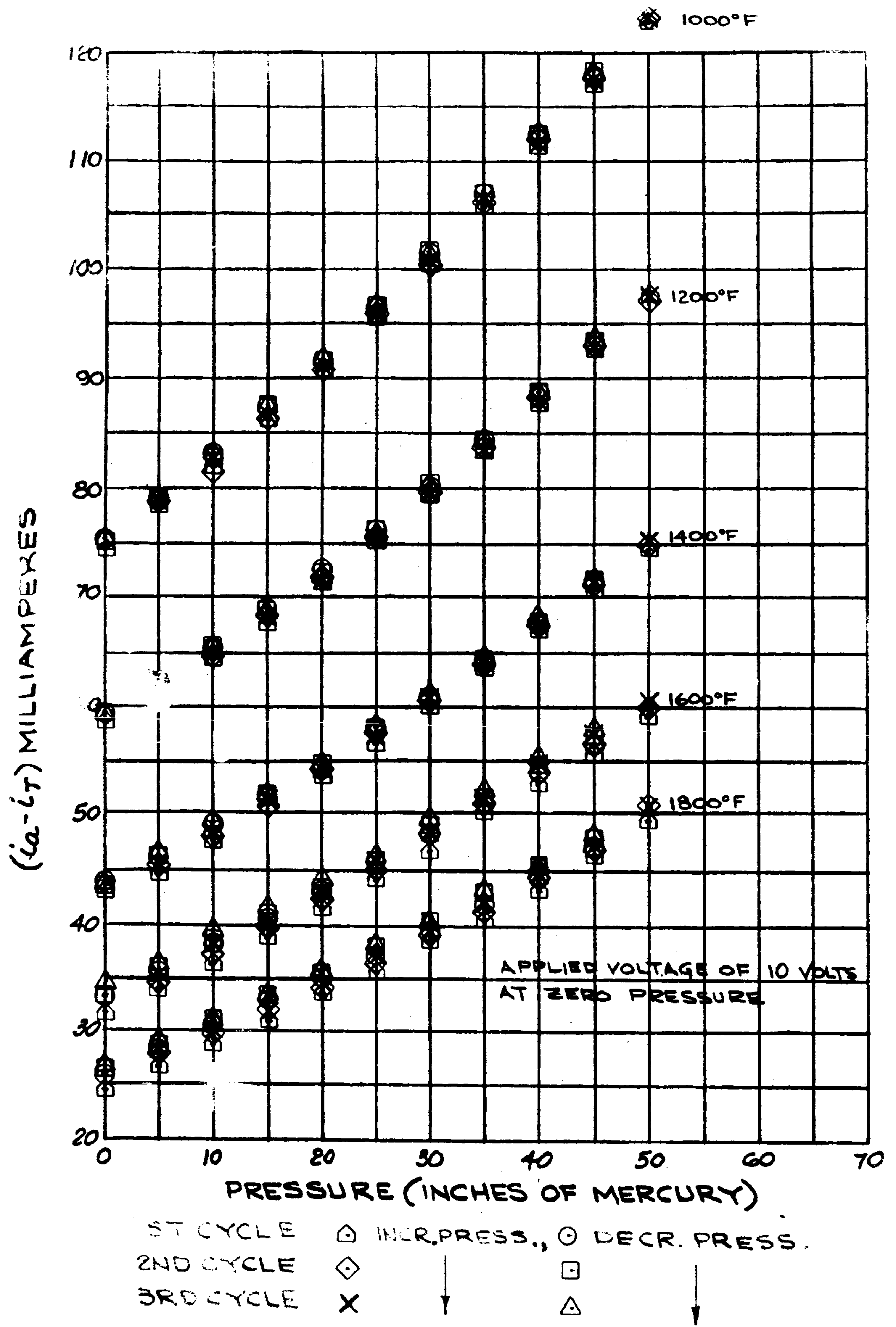


FIGURE 2

PRESSURE-OUTPUT DATA FOR DECREASING TEMPERATURE, T6 (FS-85)

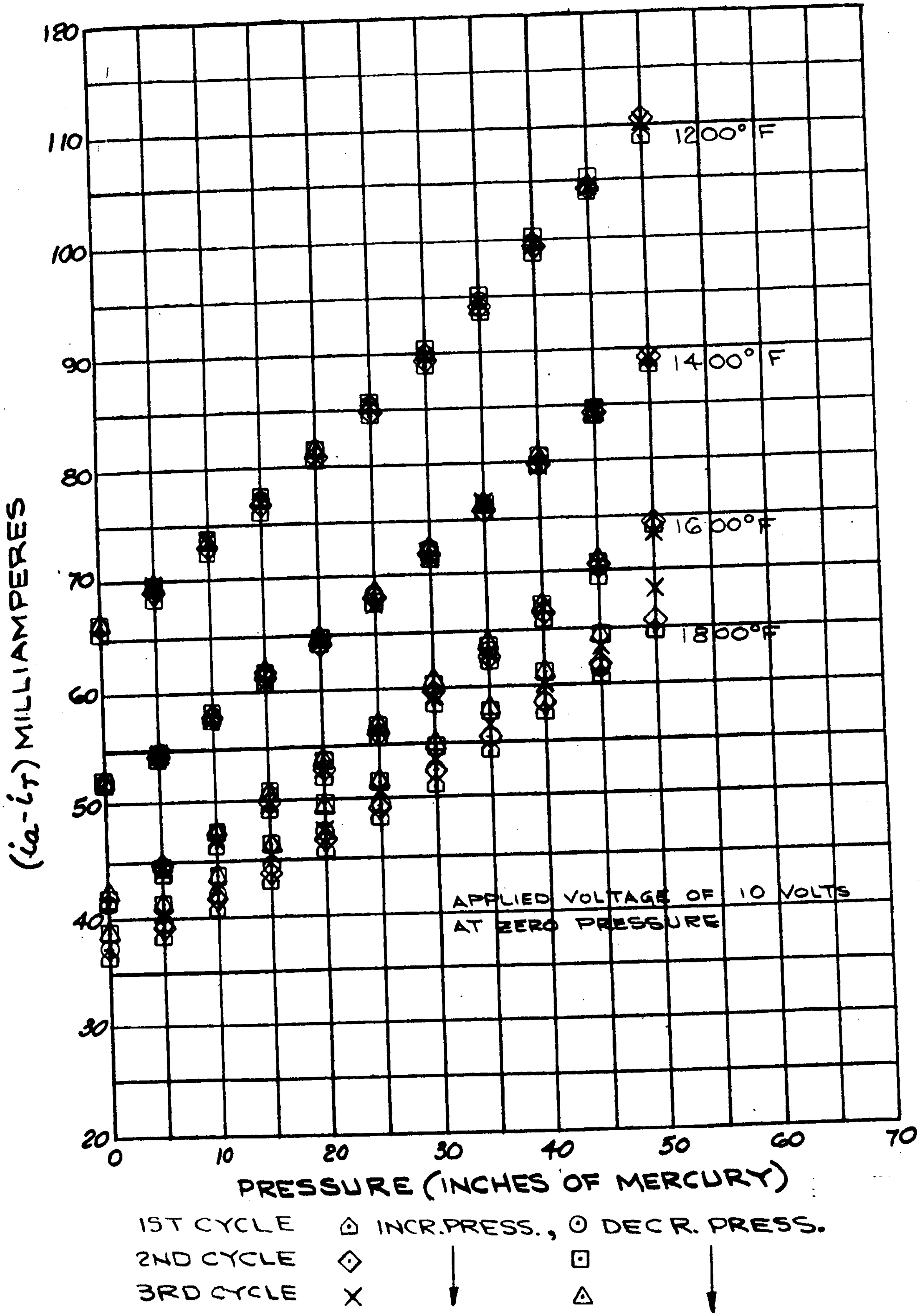


FIGURE 3

PRESSURE-OUTPUT DATA FOR INCREASING TEMPERATURE, T6 (FS-85)

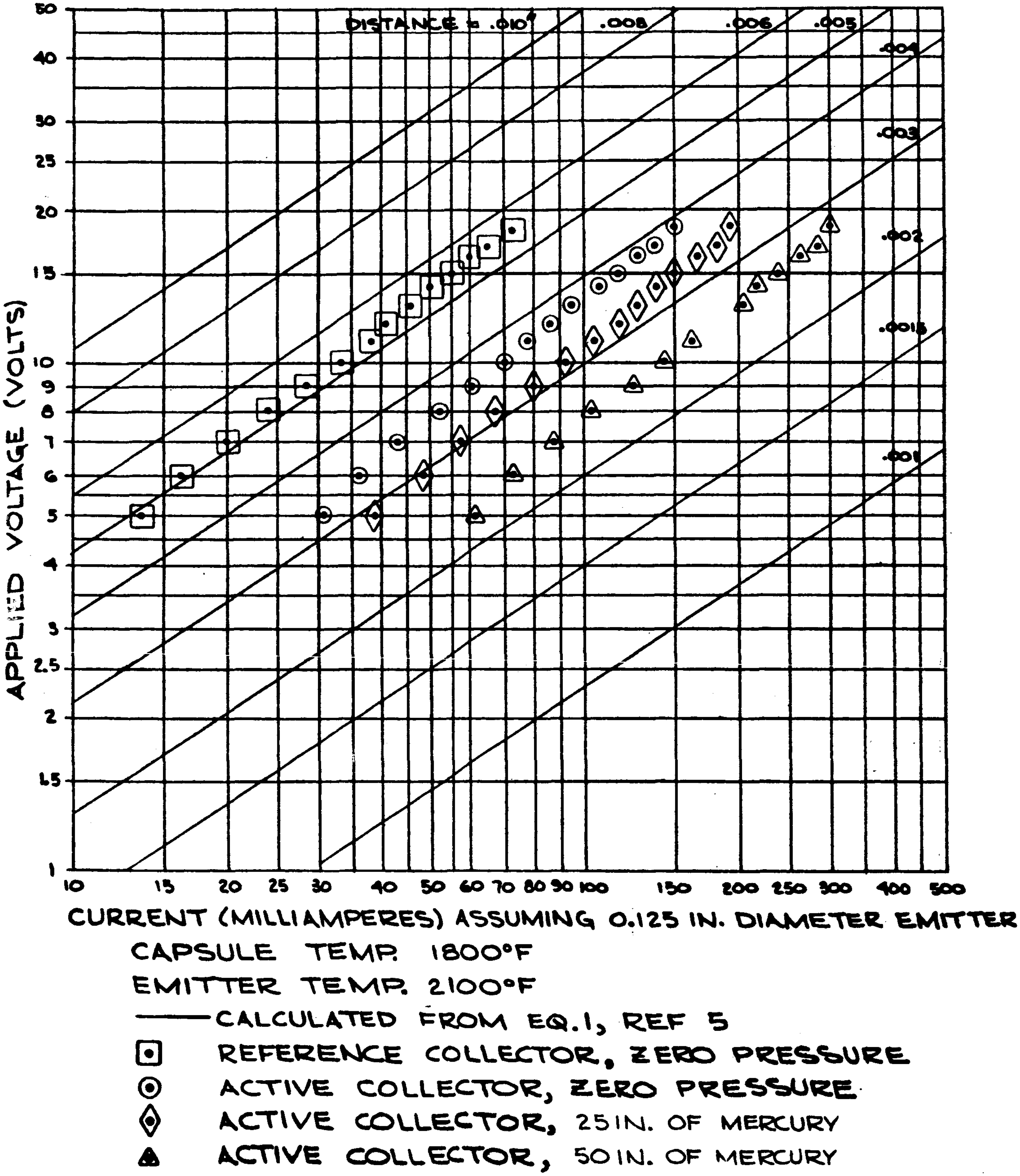


FIGURE 4

FINAL SPACE - CHARGE DATA, T-6 (FS-85)

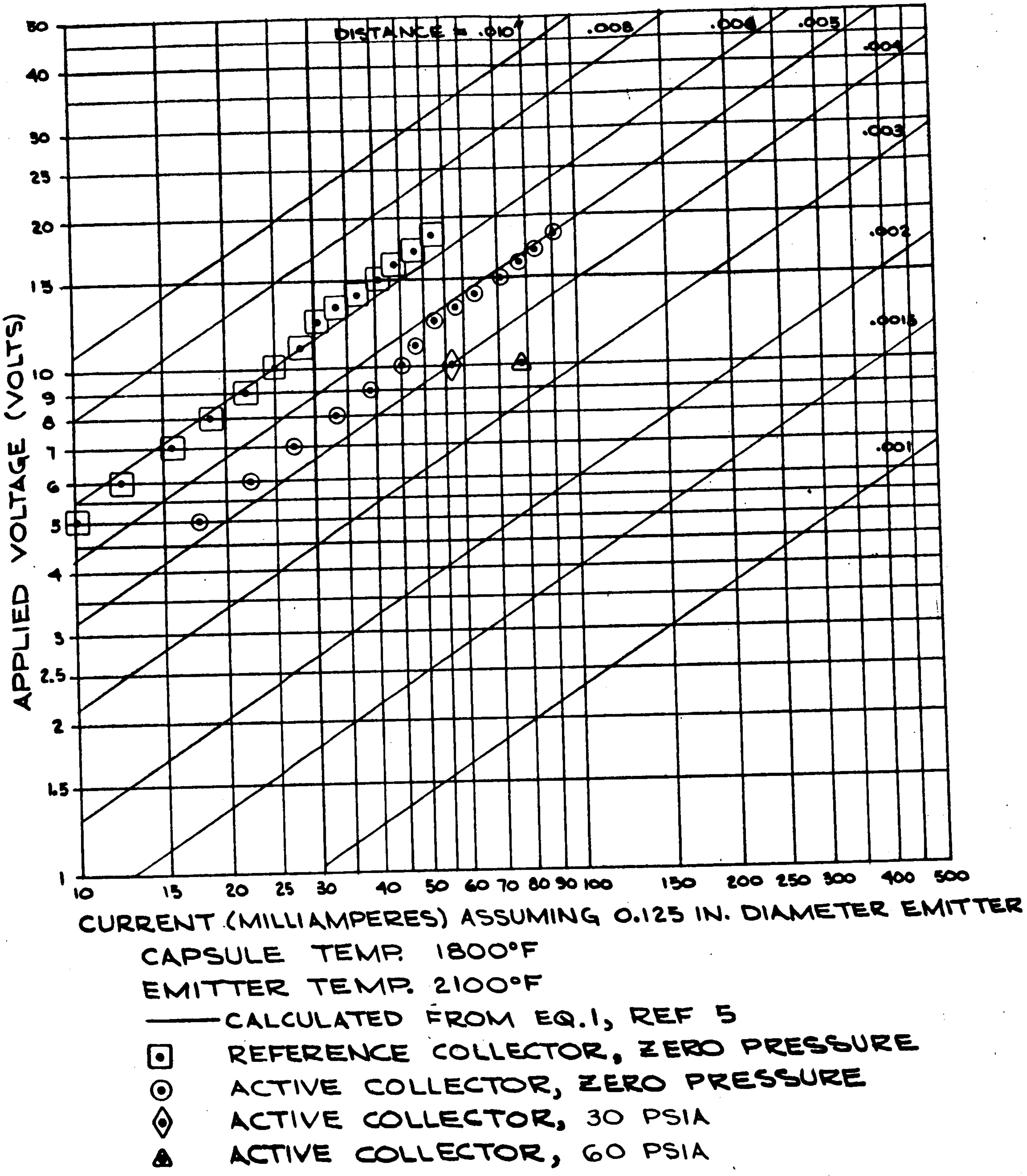


FIGURE 5

INITIAL SPACE - CHARGE DATA, T-7 (C-129Y)

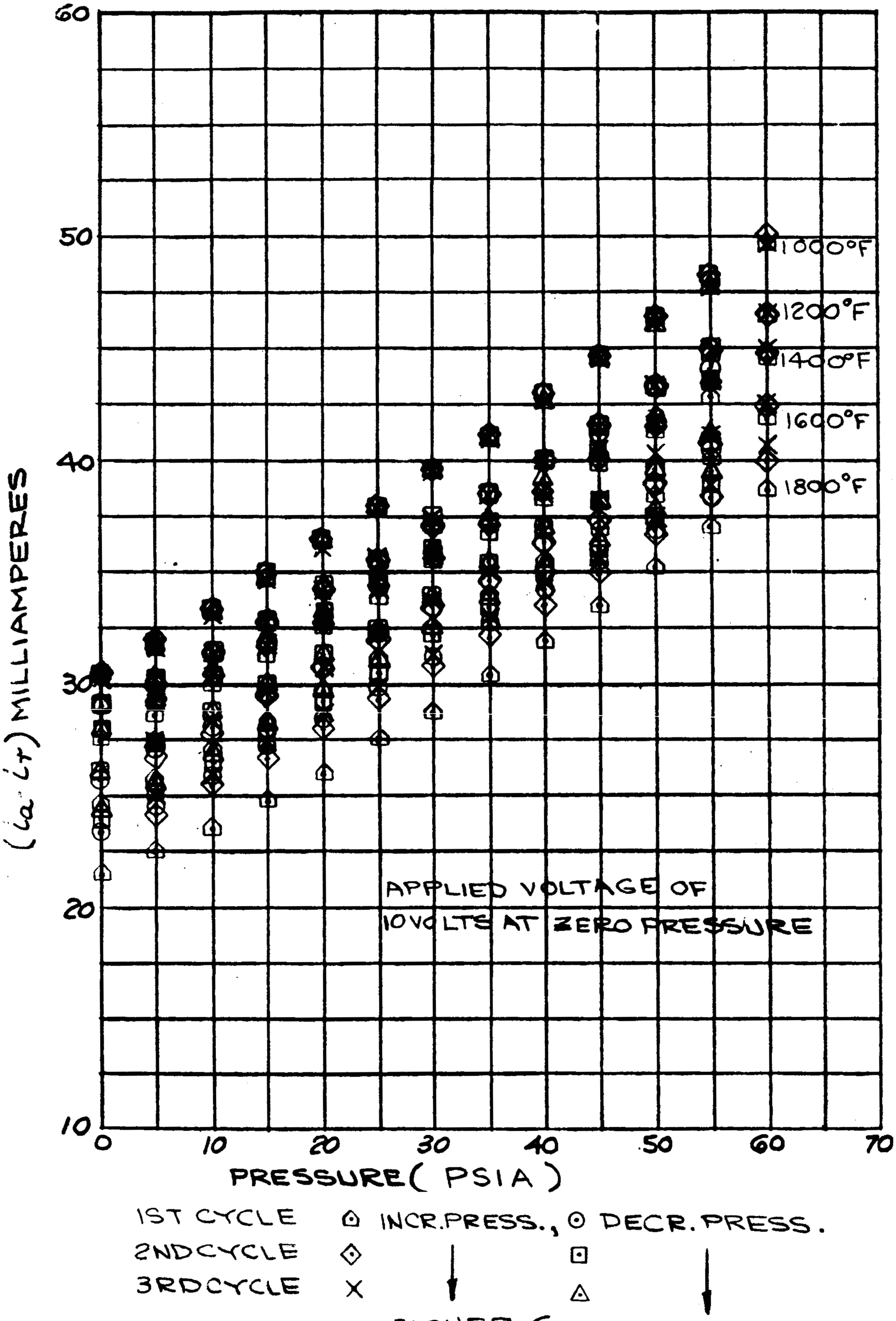
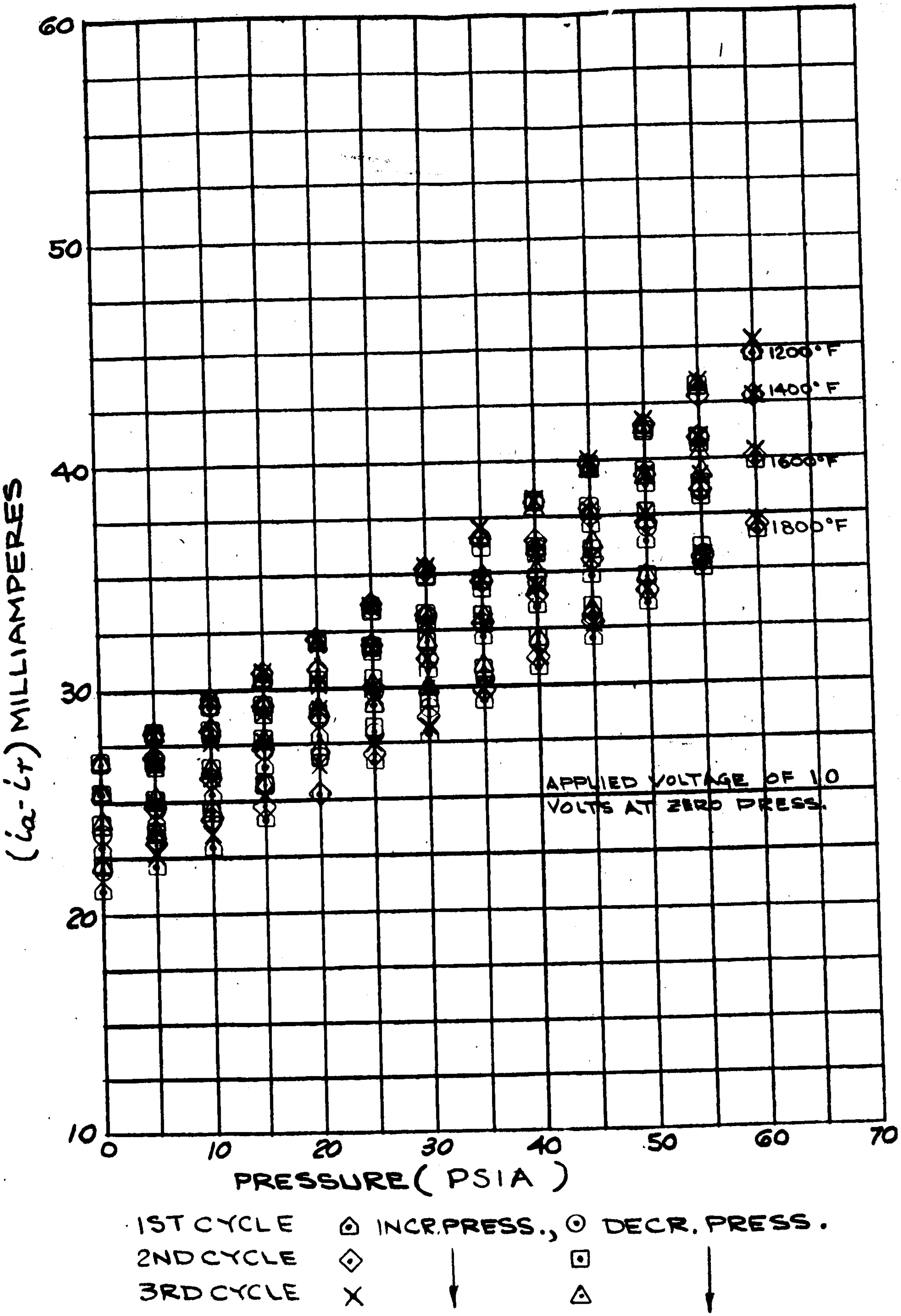


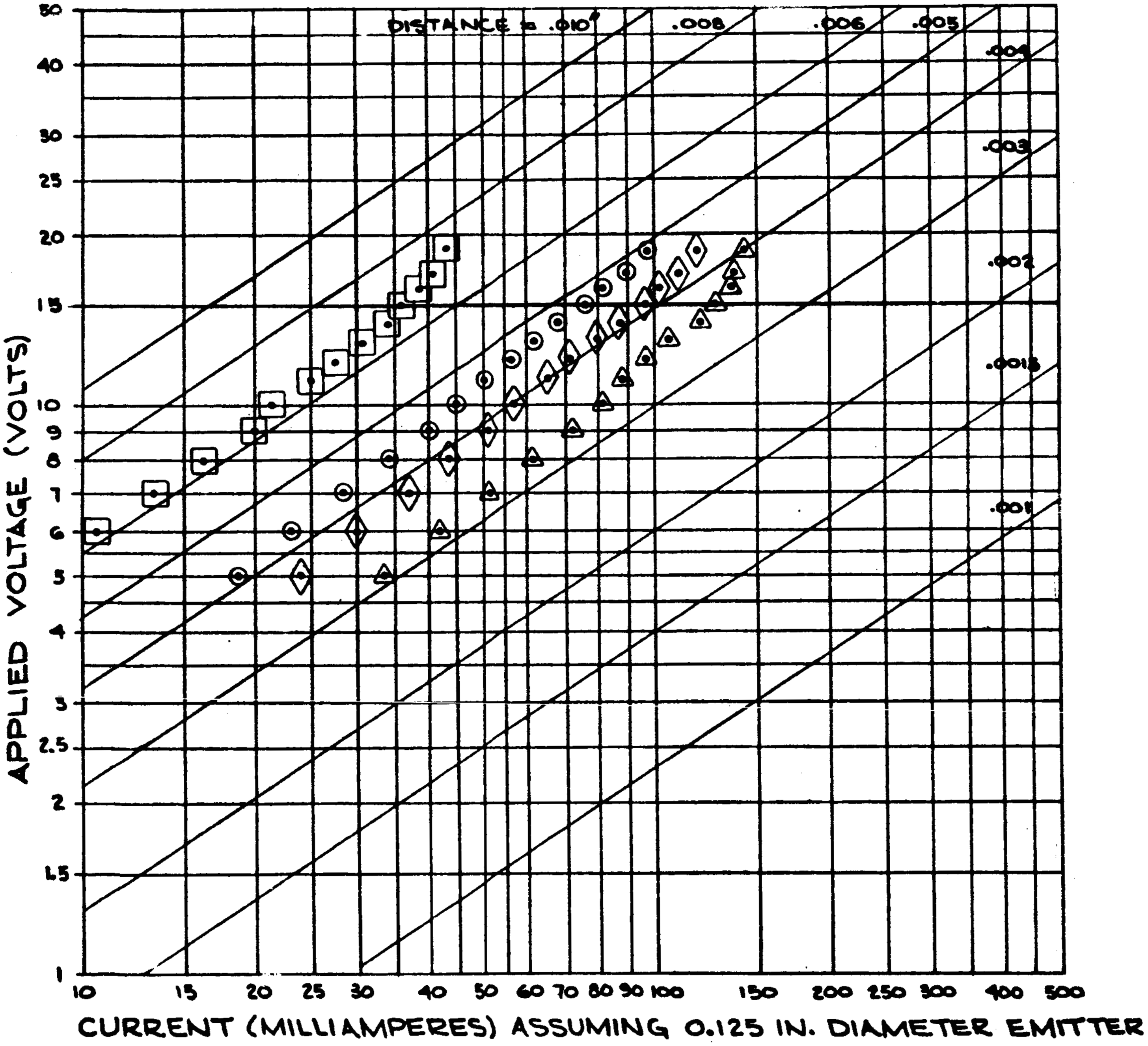
FIGURE 6

PRESSURE-OUTPUT DATA FOR DECREASING TEMPERATURE, T-7 (C-129Y)



APPLIED VOLTAGE OF 1.0 VOLTS AT ZERO PRESS.

FIGURE 7
PRESSURE - OUTPUT DATA FOR INCREASING TEMP., T-7 (G-129Y)



CAPSULE TEMP. 1800°F

EMITTER TEMP. 2100°F

——— CALCULATED FROM EQ. 1, REF 5

⊡ REFERENCE COLLECTOR, ZERO PRESSURE

⊙ ACTIVE COLLECTOR, ZERO PRESSURE

◈ ACTIVE COLLECTOR, 30 PSIA

▲ ACTIVE COLLECTOR, 60 PSIA

FIGURE 8

FINAL SPACE-CHARGE DATA, T-7 (C-129Y)

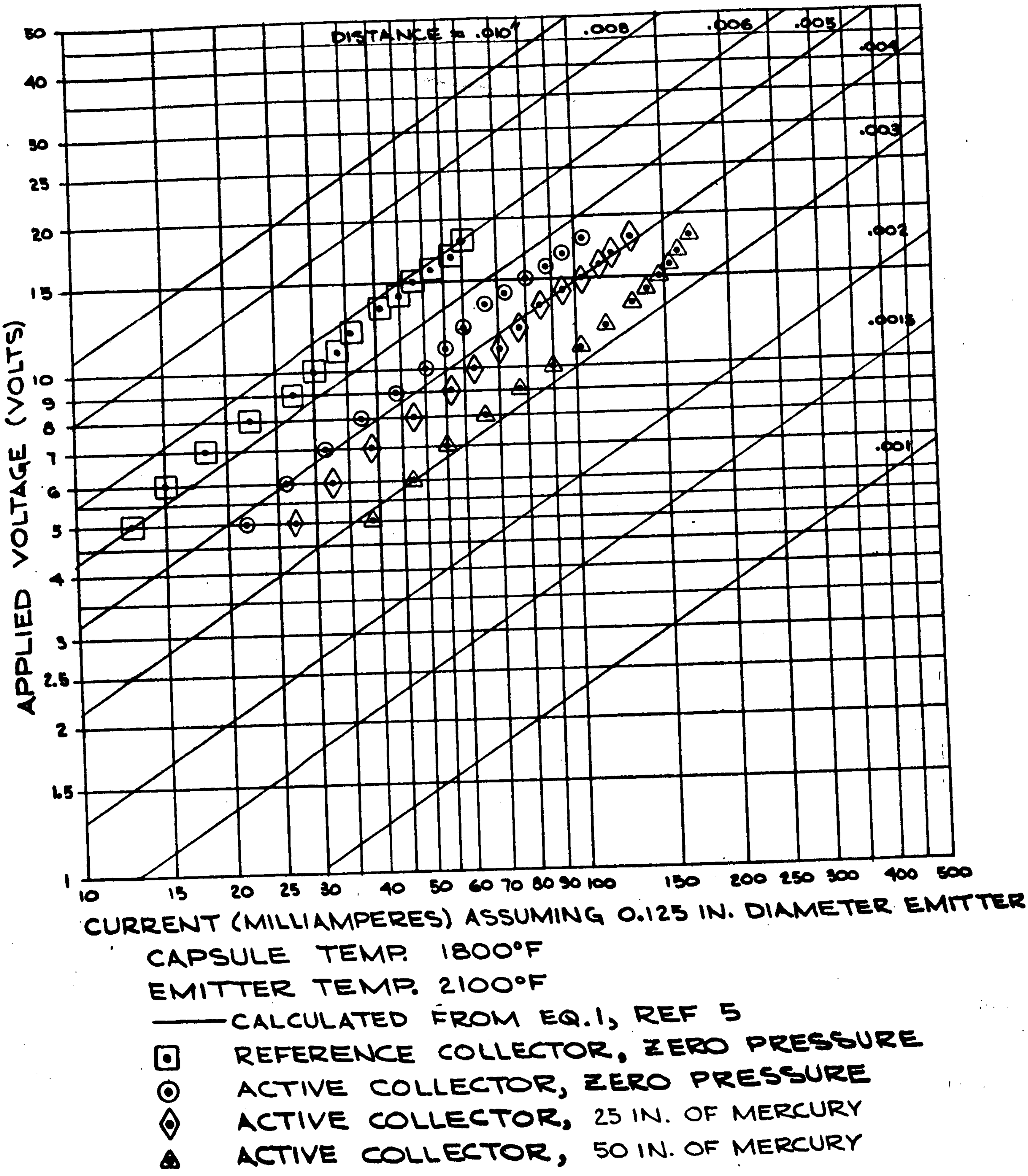


FIGURE 9

INITIAL SPACE-CHARGE DATA, T-6 (FS-85)

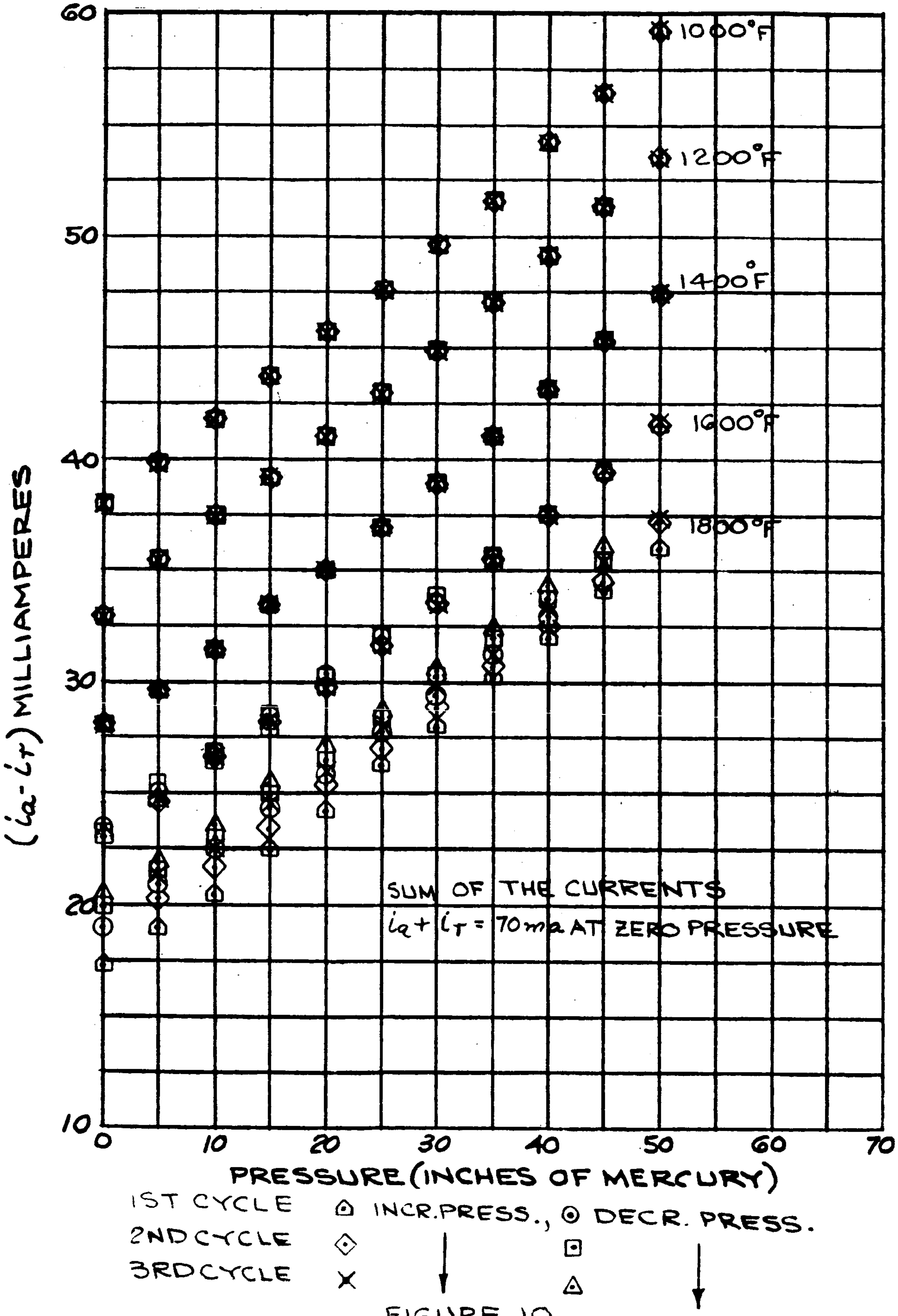


FIGURE 10

PRESSURE-OUTPUT DATA FOR DECREASING TEMPERATURE, T6 (FS-85)

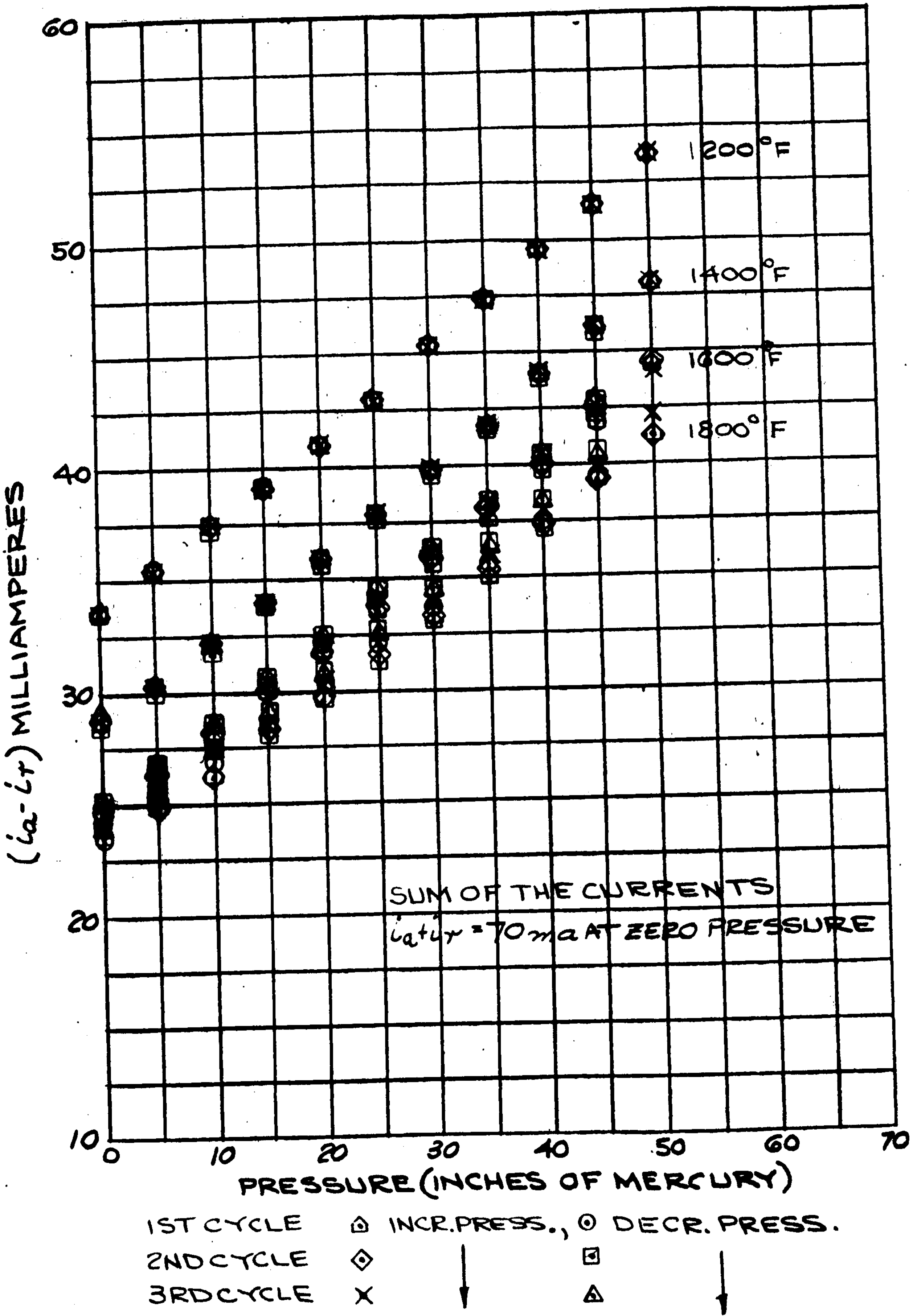


FIGURE 11

PRESSURE-OUTPUT DATA FOR INCREASING TEMPERATURE, T6 (FS-85)

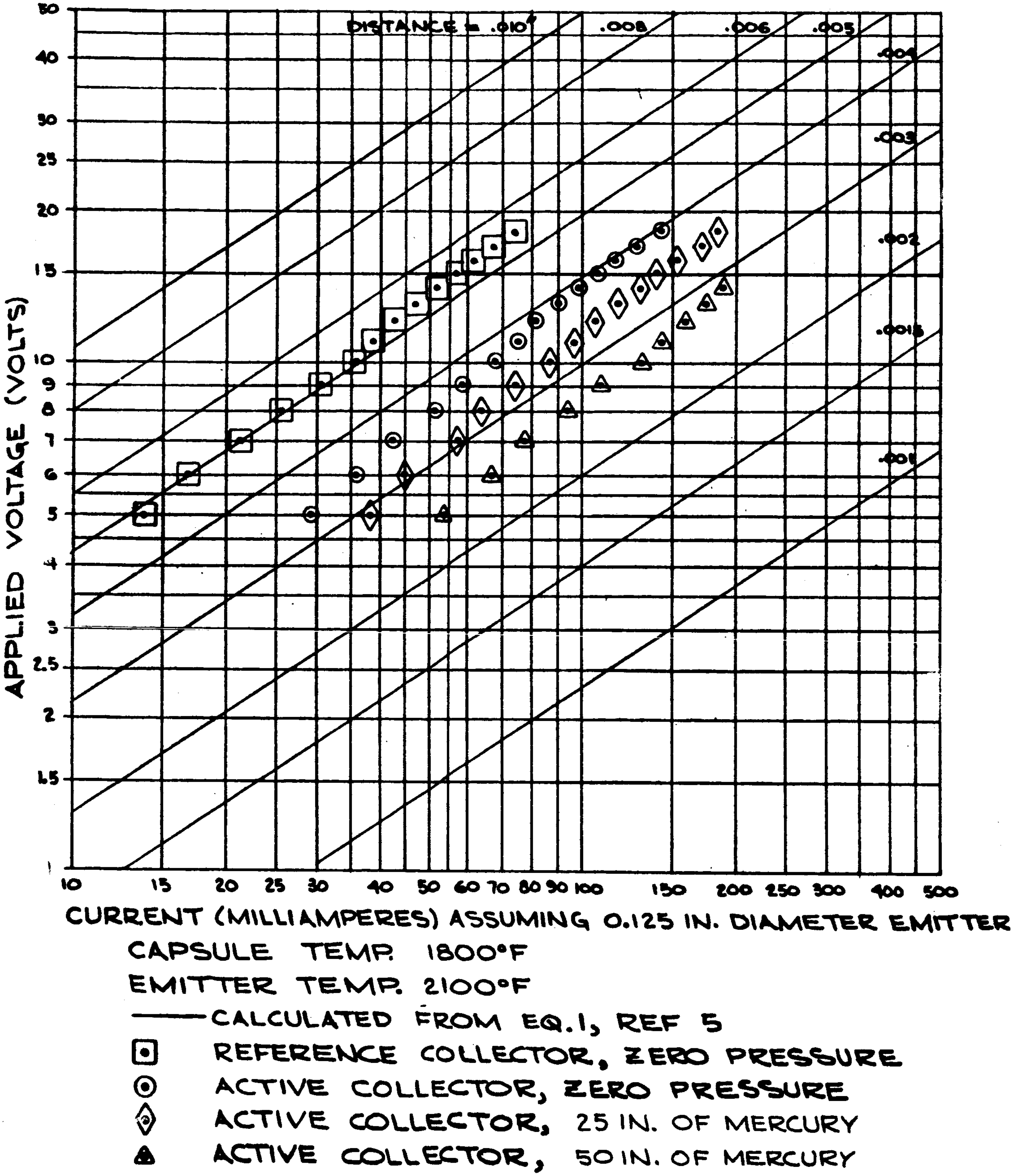


FIGURE 12

FINAL SPACE – CHARGE DATA, T-6(FS-85)

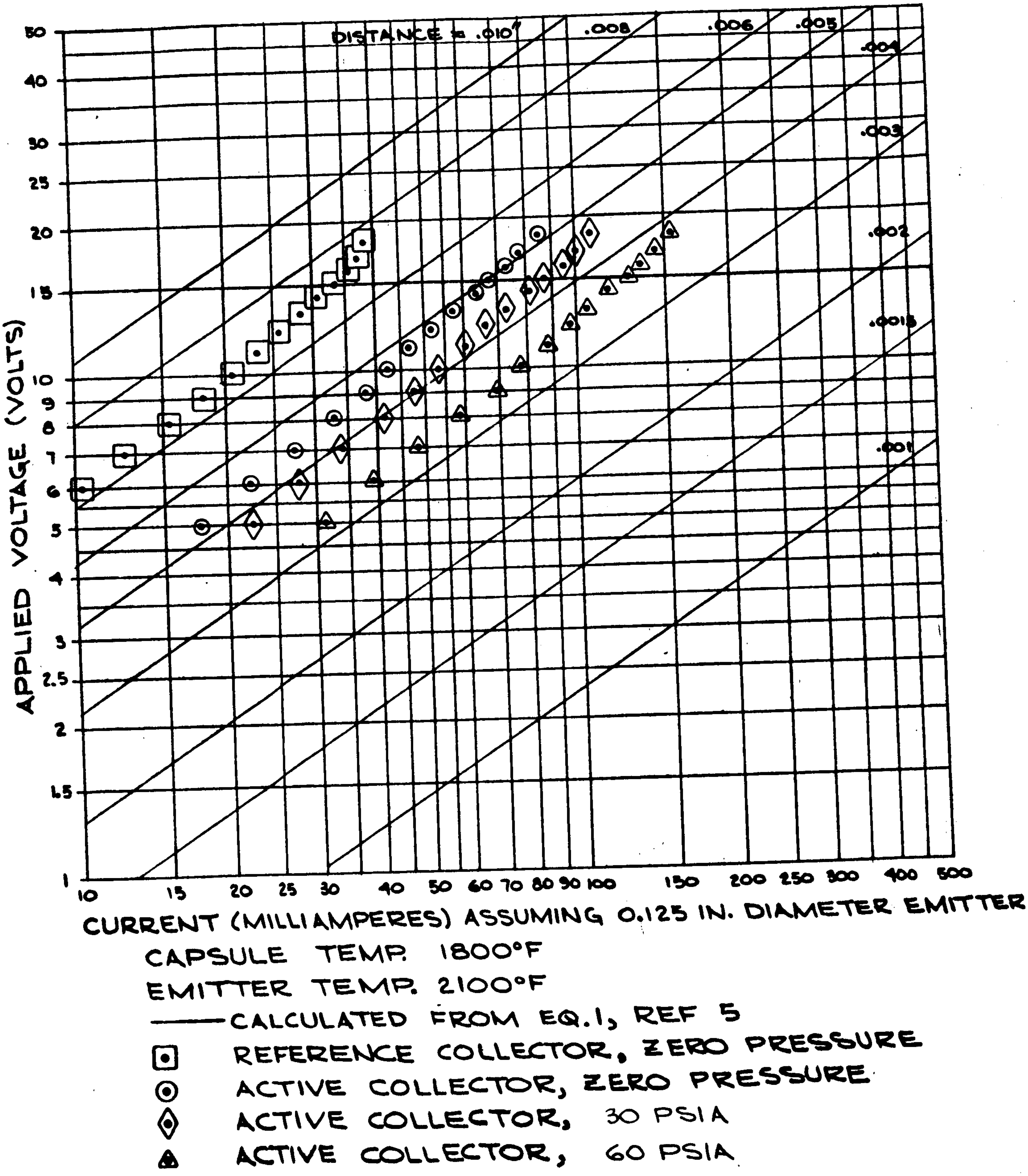


FIGURE 13

INITIAL SPACE - CHARGE DATA, T-7 (C-129Y)

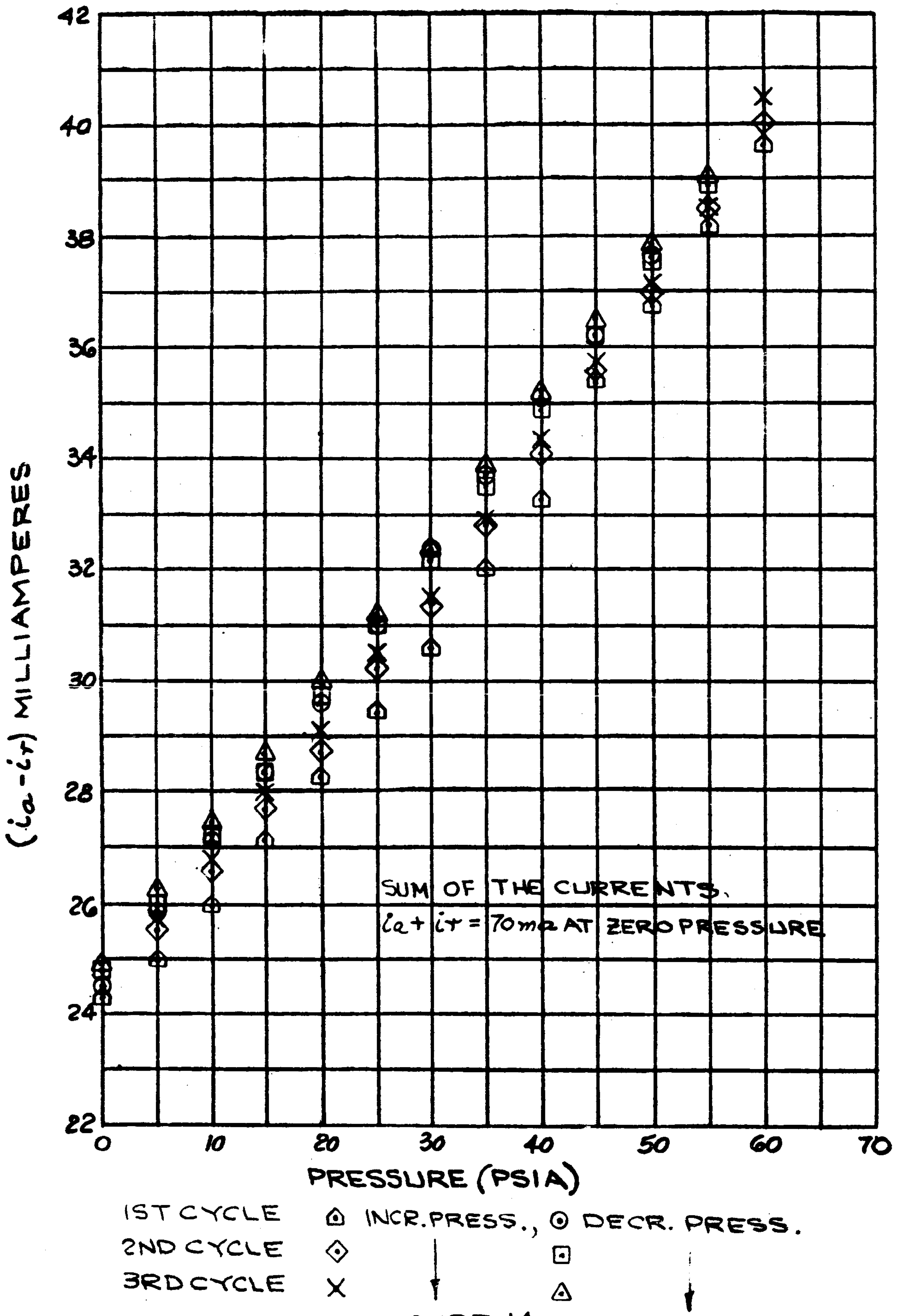


FIGURE 14
PRESSURE-OUTPUT DATA AT 1800°F, T-7 (C-129Y)

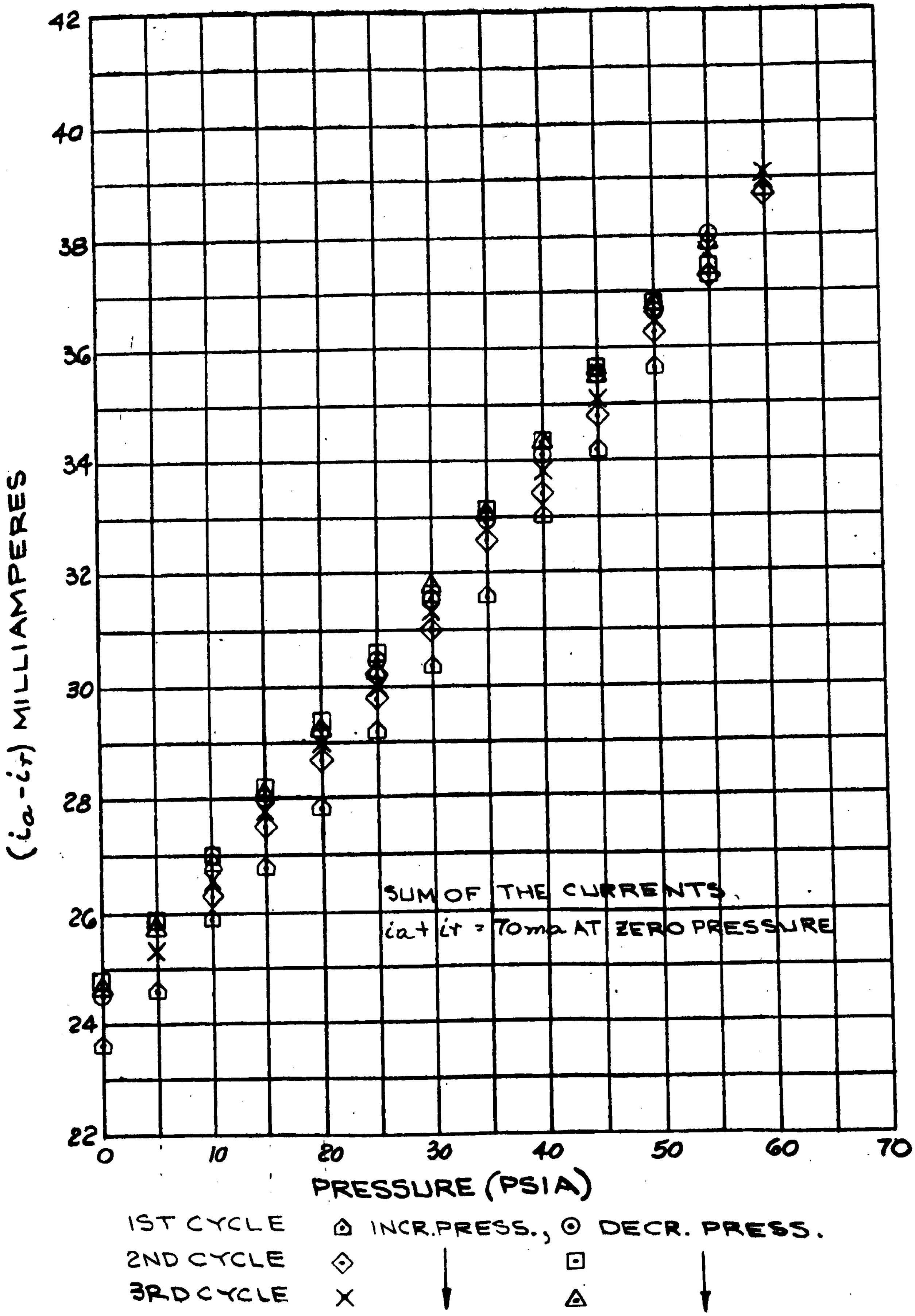


FIGURE 15

PRESSURE-OUTPUT DATA AT 1600°F, T-7 (C-129Y)

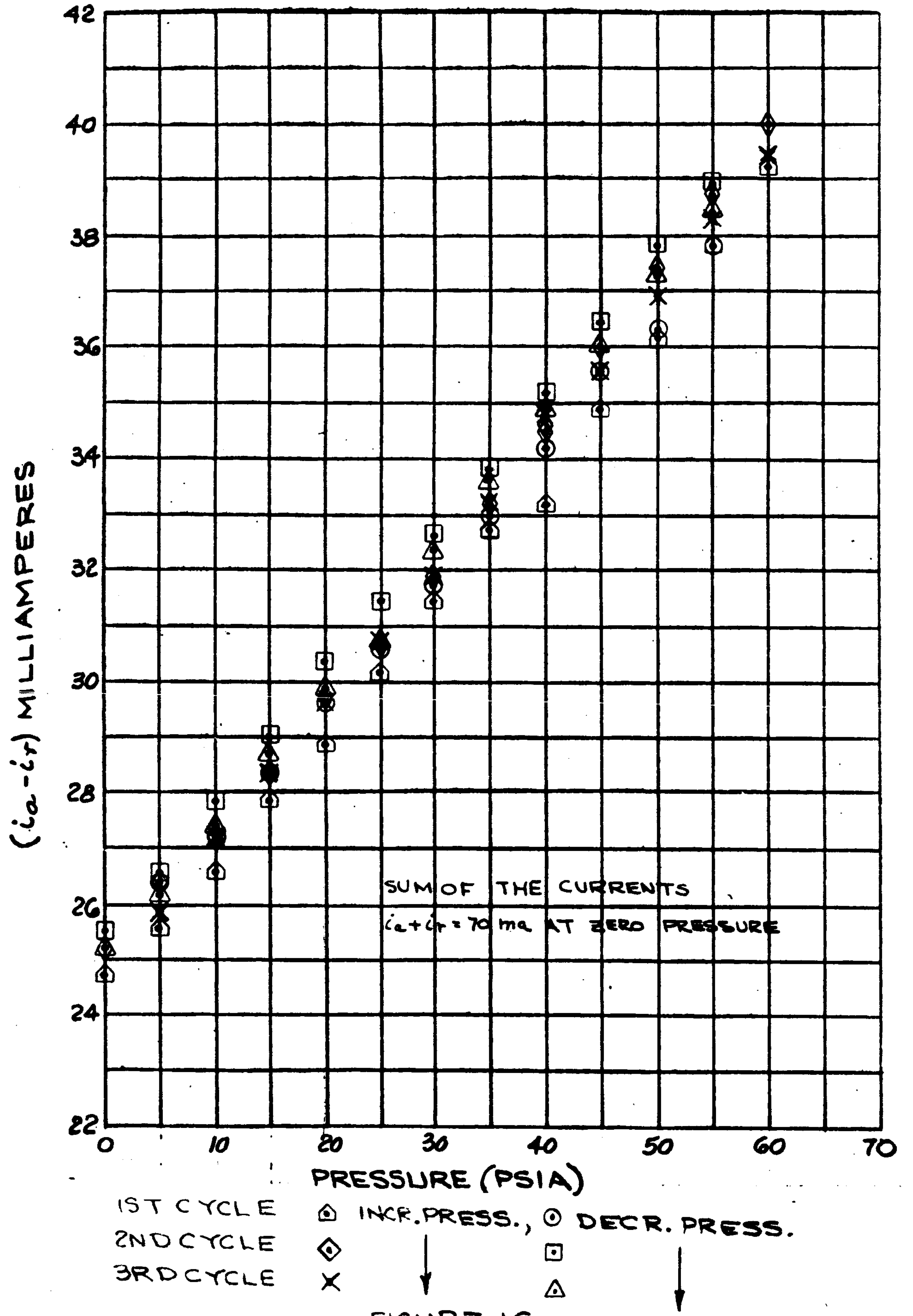


FIGURE 16
PRESSURE-OUTPUT DATA AT 1400 °F, T-7(C-129Y)

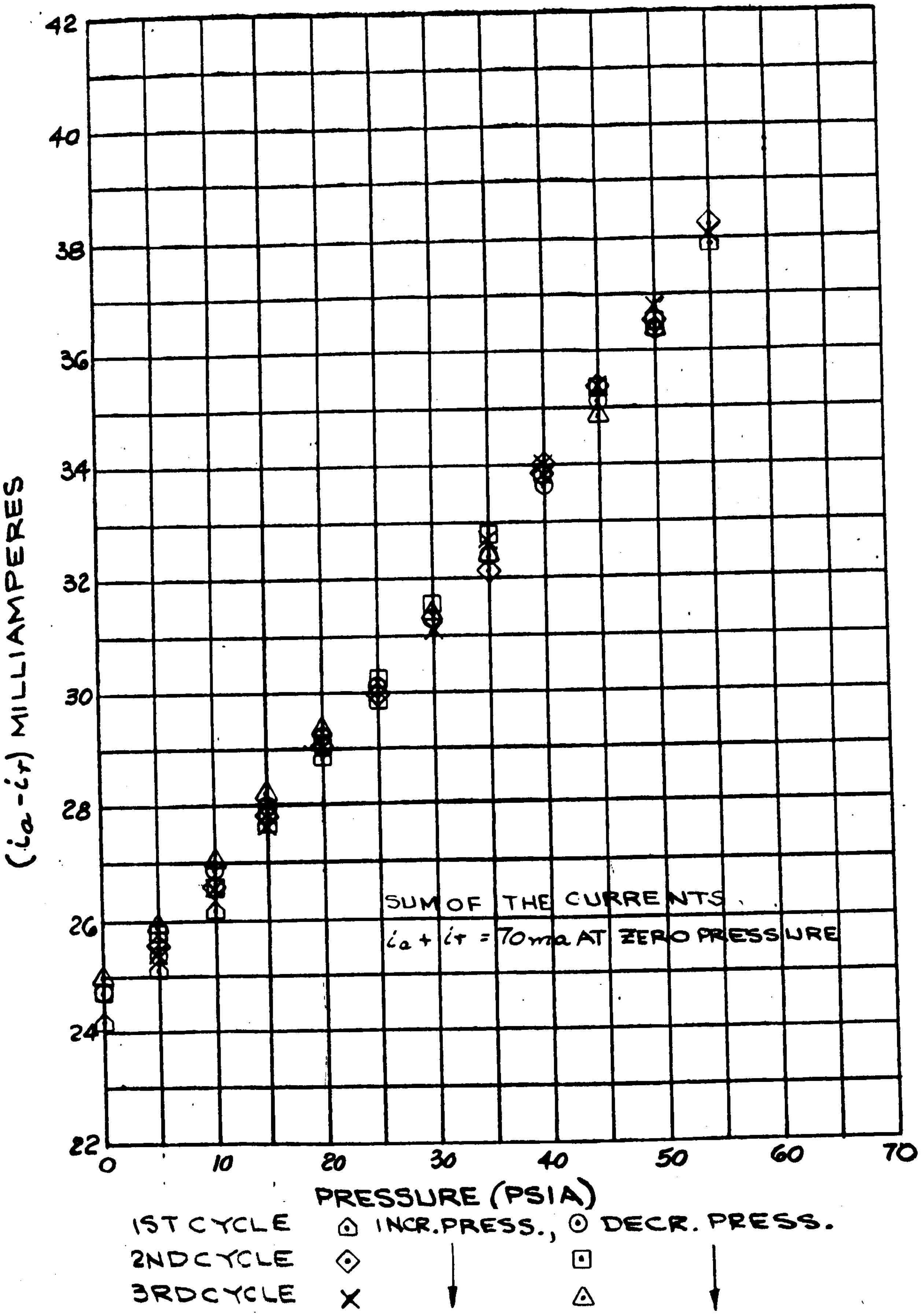


FIGURE 17

PRESSURE - OUTPUT DATA AT 1200°F, T-7 (C-129Y)

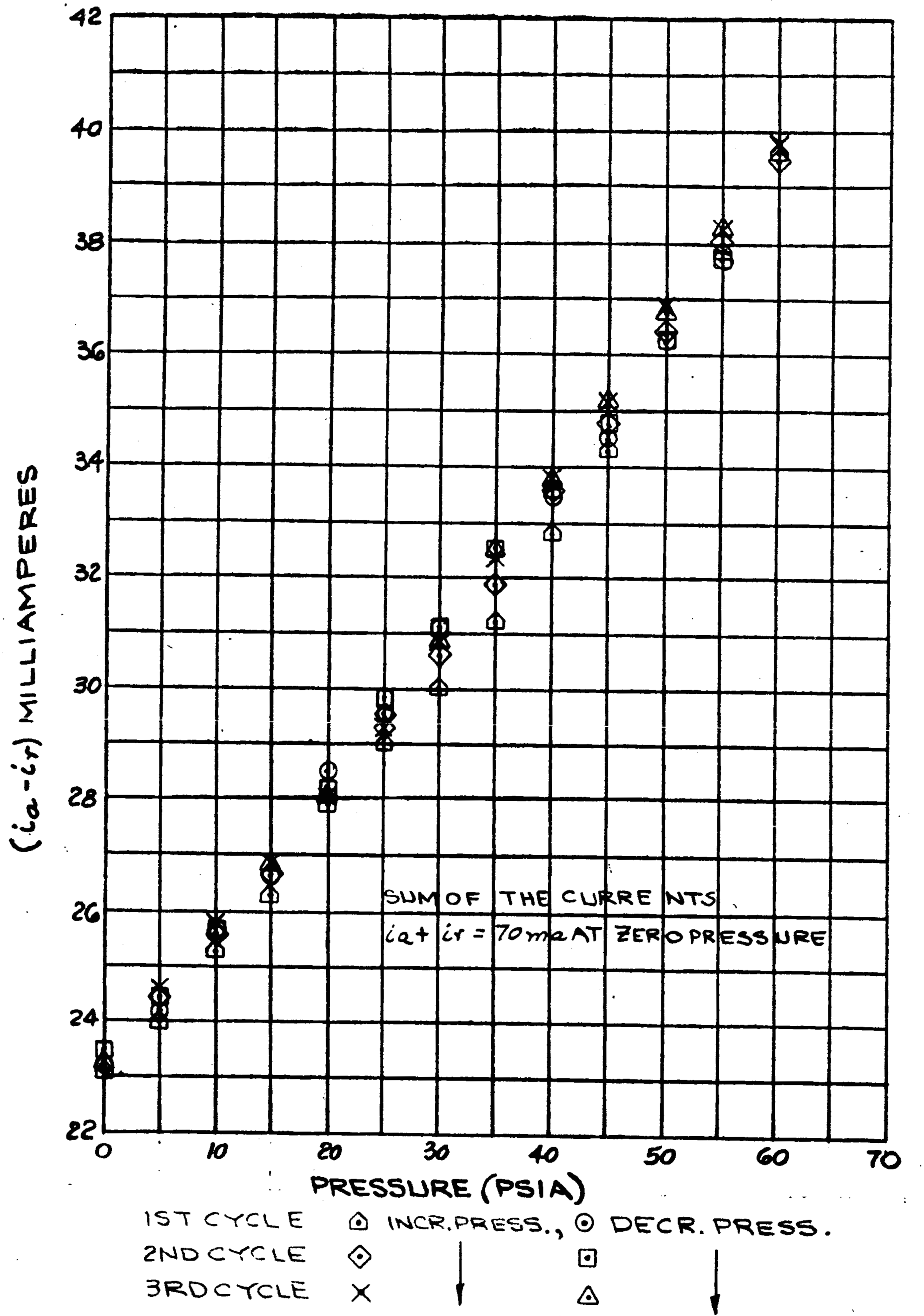


FIGURE 1B

PRESSURE-OUTPUT DATA AT 1000°F, T-7 (C-129Y)

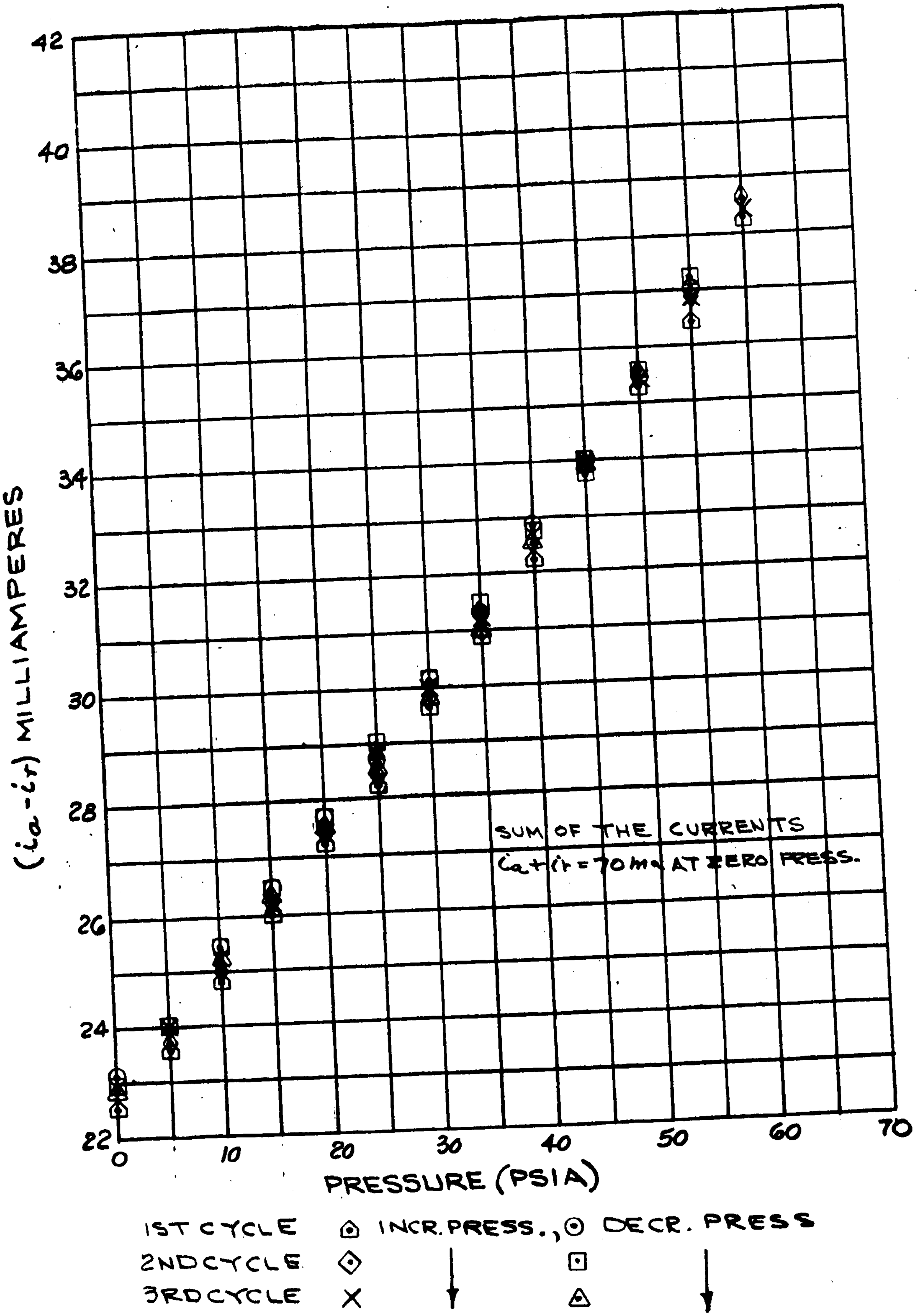


FIGURE 19

PRESSURE-OUTPUT DATA AT 1200°F, T-7 (C-129Y)

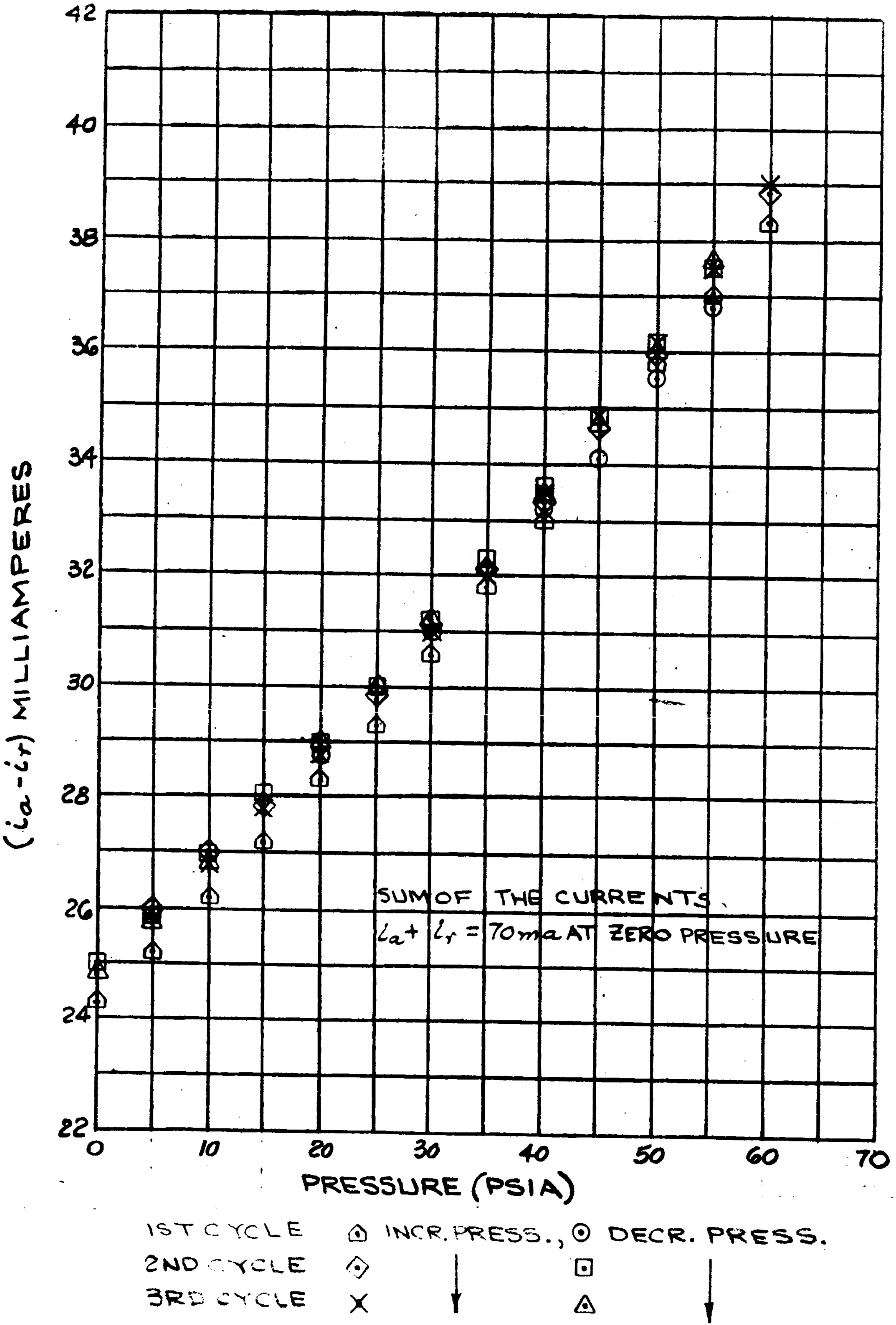


FIGURE 20

PRESSURE-OUTPUT DATA AT 1400°F, T-7 (C-129Y)

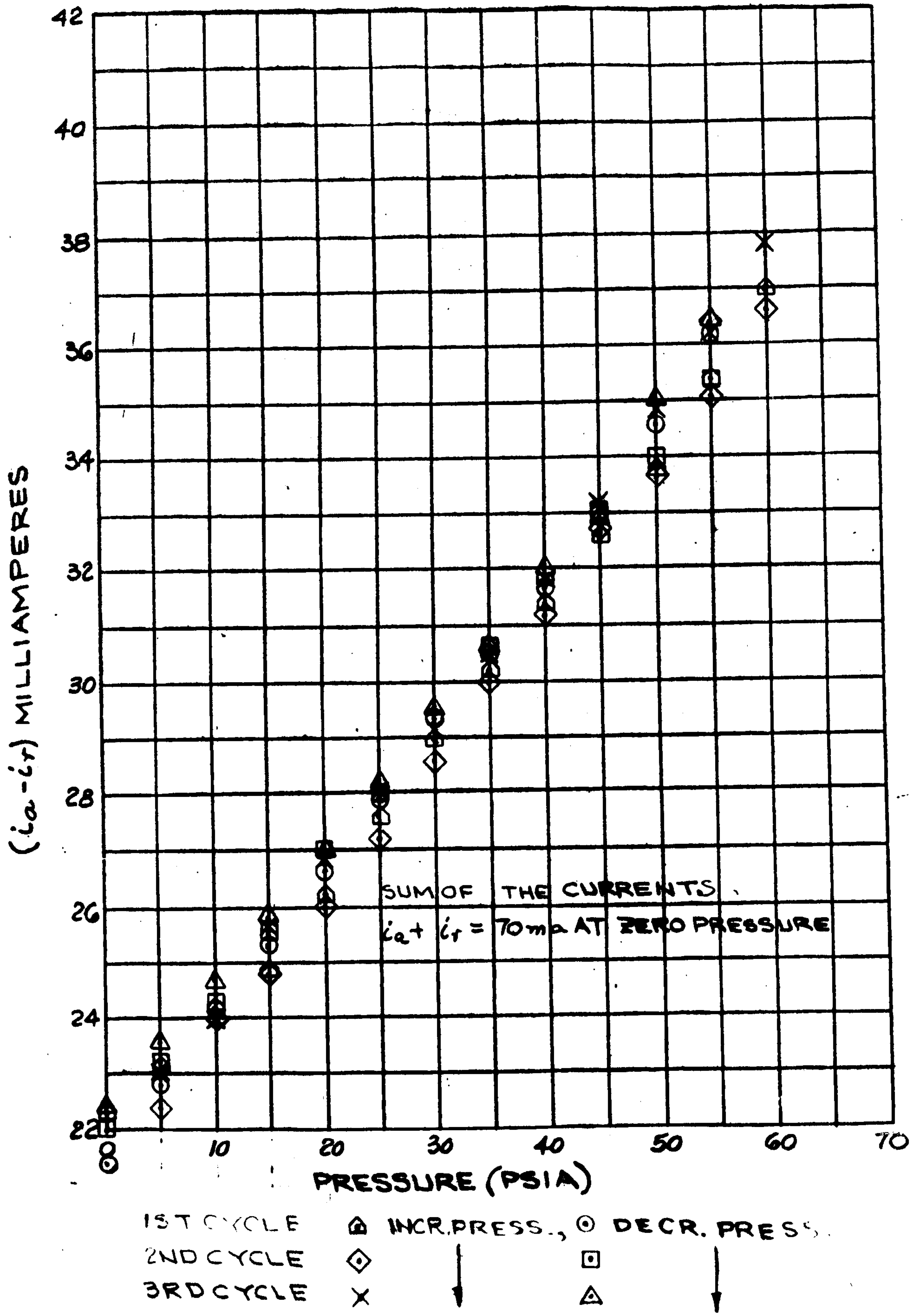


FIGURE 21

PRESSURE - OUTPUT DATA AT 1600°F, T-7 (C-129Y)

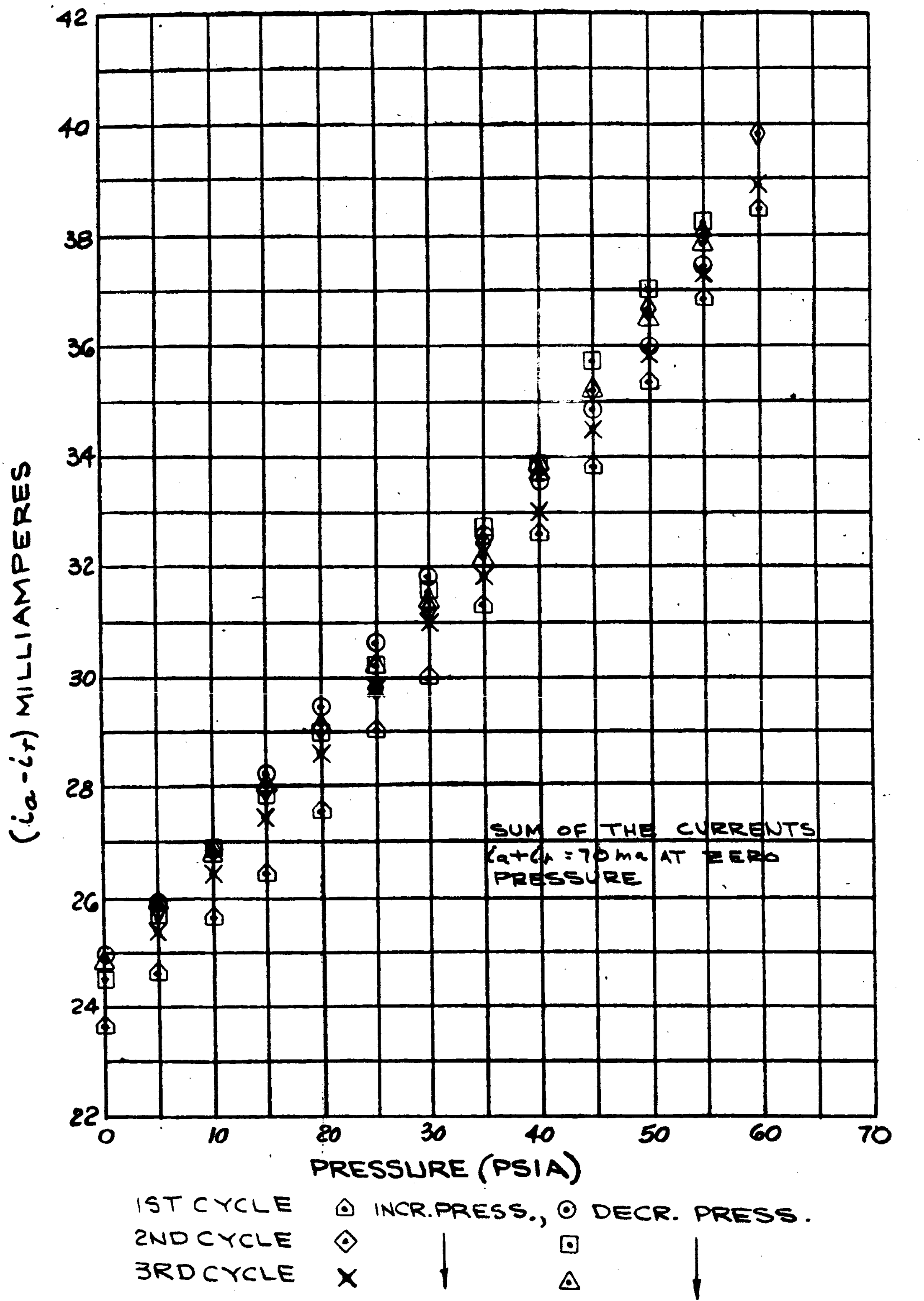


FIGURE 22
PRESSURE - OUTPUT DATA AT 1800°F, T-7 (C-129Y)

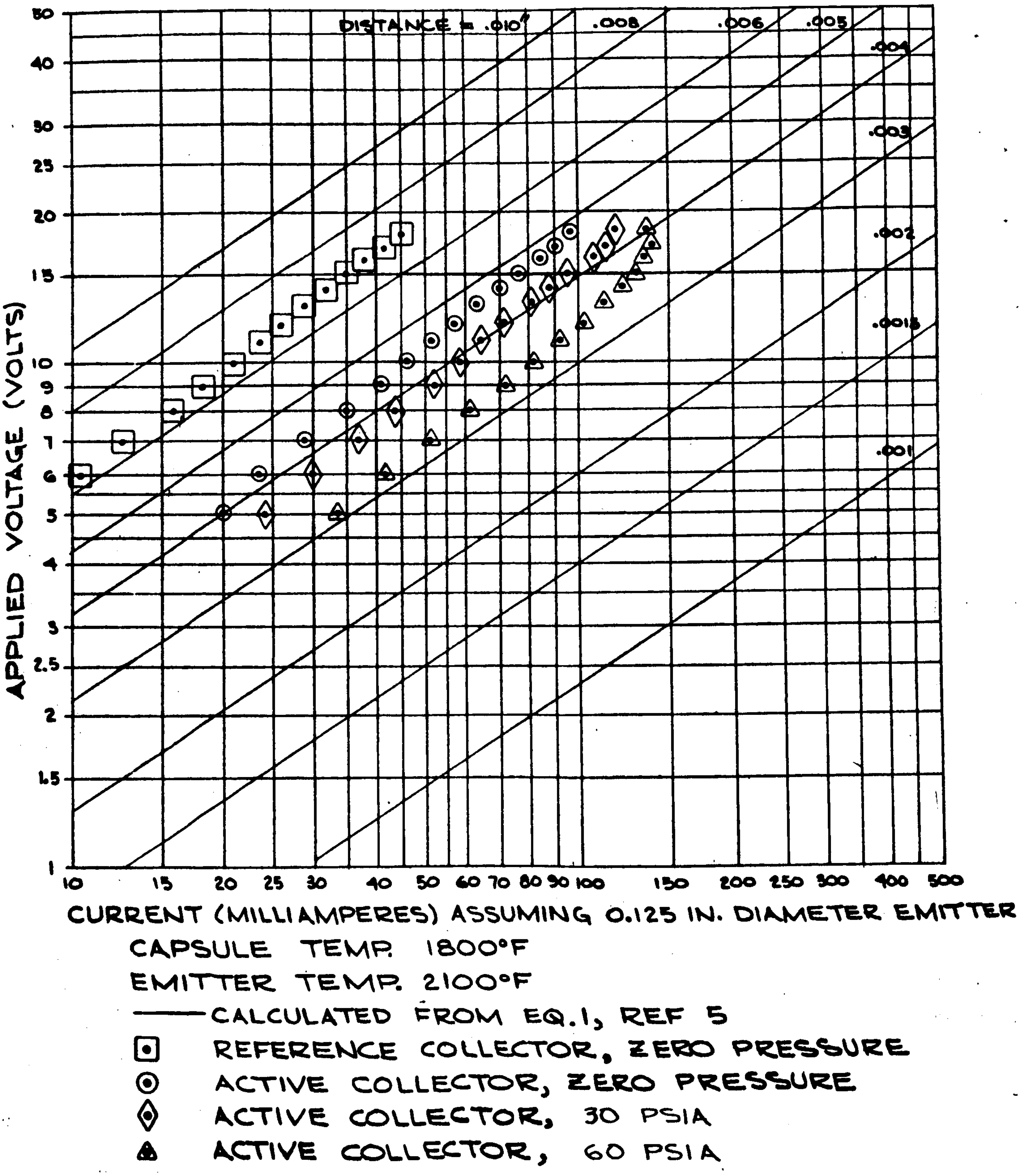


FIGURE 23

FINAL SPACE – CHARGE DATA, T-7 (C-129Y)

LIST OF REFERENCES

1. Cassano, Anthony J.: Seventh Quarterly Report Pressure Measuring Systems for Closed Cycle Liquid Metal Facilities. NASA CR-54899, January 25, 1966.

2. Cassano, Anthony J.: Fourth Quarterly Report Pressure Measuring Systems for Closed Cycle Liquid Metal Facilities. NASA CR-54371, April 5, 1965.

3. Cassano, Anthony J.: Fifth Quarterly Report Pressure Measuring Systems for Closed Cycle Liquid Metal Facilities. NASA CR-54439, June 28, 1965.

4. Cassano, Anthony J.: Sixth Quarterly Report Pressure Measuring Systems for Closed Cycle Liquid Metal Facilities. NASA CR-54763, October 18, 1965.

5. Engdahl, R. E., ed.: First Quarterly Report Pressure Measuring Systems for Closed Cycle Liquid Metal Facilities. NASA CR-54140, July 2, 1964.

DISTRIBUTION LIST

Recipient	No. of Copies
National Aeronautics & Space Administration Washington, D. C. 20546 Attention: J. J. Lynch, Code RNP	1
U. S. Atomic Energy Commission Washington, D. C. 20545 Attention: SNAP-50/SPUR Program Office Herbert D. Rochen	1
National Aeronautics & Space Administration Ames Research Center Moffett Field, California 94035 Attention: Library	1
National Aeronautics & Space Administration Goodard Space Flight Center Greenbelt, Maryland 20771 Attention: Library	1
National Aeronautics & Space Administration Jet Propulsion Laboratory 4800 Oak Grove Drive Pasadena, California 91103 Attention: Library	1
J. P. Davis	1
National Aeronautics & Space Administration Langley Research Center Langley Station Hampton, Virginia 23365 Attention: Library	1
National Aeronautics & Space Administration Electronic Research Center 575 Technology Square Cambridge, Massachusetts, 02139 Attention: Dr. James Cline Electronic Component Branch	1

DISTRIBUTION LIST (CONTINUED)

Recipient	No. of Copies
National Aeronautics & Space Administration Lewis Research Center 21000 Brookpark Road Cleveland, Ohio 44135	
Attention: Library (3-7)	1
Technology Utilization Office (3-16)	1
Office of Development Evaluation and Management Review (500-203)	1
Dr. B. Lubarsky (500-201)	1
R.L.Cummings (500-201)	1
R. N. Weltmann (500-309)	2
R. R. Miller (500-202)	1
H. O. Slone (500-201)	1
M. J. Saari (500-202)	1
C. C. Gettelman (77-1)	1
D. R. Englund, Jr. (77-1)	1
Dr. L. Rosenblum (106-1)	1
H. H. Christenson (5-3)	1
J. E. Dilley (500-309)	1
M. O. Dustin (54-1)	1
E. A. Koutnik (500-201)	1
R. A. Lindberg (500-309)	1
Report Control Office (5-5)	1
National Aeronautics & Space Administration George C. Marshall Space Flight Center Huntsville, Alabama 35812	
Attention: Library	1
National Aeronautics & Space Administration Scientific & Technical Information Facility P. O. Box 5700 Bethesda, Maryland, 20014	
Attention: NASA Representative	6

DISTRIBUTION LIST (CONTINUED)

Recipient	No. of Copies
Air Force Systems Command	
Aeronautical Systems Division	
Wright-Patterson AFB, Ohio 45433	
Attention: Library (EWABE)	1
C. L. Delaney (APIP-1)	1
J. W. Zmurk (APIP-1)	1
G. E. Thompson (APIP-1)	1
G. Sherman (API)	1
U. S. Atomic Energy Commission	
Germantown, Maryland 20767	
Attention: Carl Johnson	1
Reactor Power Systems Branch	
Argonne National Laboratory	
P. O. Box 299	
Lemont, Illinois 60439	
Attention: Library	1
Brookhaven National Laboratory	
Upton, New York 11973	
Attention: Library	1
Dr. O. E. Dwyer	1
Lawrence Radiation Laboratory	
Livermore, California 94550	
Attention: Dr. James Hadley	1
Head, Reactor Division	
Oak Ridge National Laboratory	
Oak Ridge, Tennessee 37831	
Attention: Dr. H. W. Hoffman	
Y-12 Site, Building 9204-1	1
W. O. Harms	
Metal & Ceramics Division	1

DISTRIBUTION LIST (CONTINUED)

Recipient	No. of Copies
Aerojet-General Corporation SNAP-8 Division Azusa, California 91703 Attention: Dr. Robert Gordon	1
Aerojet General Nucleonics P.O. Box 77 San Ramon, California 94583 Attention: K. P. Johnson	1
AiResearch Manufacturing Company Division of the Garrett Corporation 402 South 36th Street Phoenix, Arizona 85034 Attention: J. Dennan	1
The Bendix Corporation Research Laboratories Division Southfield, Michigan 48076 Attention: Reports Library	1
Data Sensors, Incorporated 13112 Crenshaw Boulevard Gardena, California 90249 Attention: J. M. DeStefano	1
Electro-Optical Systems, Inc. 300 N. Halstead Street Pasadena, California 91107 Attention: Dr. J. M. Teem J. C. Sanchez	1 1
Endevco Corporation 801 South Arroyo Parkway Pasadena, California 91109 Attention: Library	1

DISTRIBUTION LIST (CONTINUED)

Recipient	No. of Copies
Ford Instrument Company Division of the Sperry Rand Corporation 31-10 Thomson Avenue Long Island City, New York 11101 Attention: Lionel Leavitt	1
General Electric Company Missile and Space Division Space Power & Propulsion Section Cincinnati, Ohio 45215 Attention: E. Schnetzer	1
General Motors Corporation Allison Division P. O. Box 894 Indianapolis, Indiana 46206 Attention: Dr. F. G. Meyers	1
Gulton Industries, Incorporated Instrumentation Division 212 Durham Avenue Metuchen, New Jersey 08841 Attention: Dr. W. Welkowitz	1
Schaevitz-Bytrex Corp. 50 Hunt Street Newton, Massachusetts 02158 Attention: Malcolm Green	1
Materials Research Corporation Orangeburg, New York 10962 Attention: Dr. G. T. Murray	1
McGraw-Edison Company Thomas A. Edison Research Laboratory West Orange, New Jersey 07052 Attention: Library	1

DISTRIBUTION LIST (CONTINUED)

Recipient	No. of Copies
MSA Research Corporation Callery, Pennsylvania 16024 Attention: Dr. R. C. Werner	1
North American Aviation, Incorporated Atomics International Division P. O. Box 309 Canoga Park, California 91303 Attention: Dr. L. Bernath Library	1 1
North American Aviation, Incorporated Rocketdyne Division 6633 Canoga Avenue Canoga Park, California 91303 Attention: V. R. Degner	1
Physical Sciences Corporation 314 East Live Oak Avenue Arcadia, California 91006 Attention: J. Howard Pitt	1
Trans-Sonics, Incorporated Pressure Instrumentation Division Burlington, Massachusetts 02103 Attention: R. E. Jackson	1
United Aircraft Corporation Pratt & Whitney Aircraft Division East Hartford, Connecticut 06108 Attention: Library	2
West Coast Research Corporation 2102 South Sepulveda Boulevard Los Angeles, California 90025 Attention: H. M. Spivack	1

DISTRIBUTION LIST (CONTINUED)

Recipient	No. of Copies
Westinghouse Electric Corporation Astronuclear Laboratory P. O. Box 10864 Pittsburgh, Pennsylvania 15236 Attention: W. D. Pouchot	1
Westinghouse Electric Corporation Aerospace Electric Division Lima, Ohio 45801 Attention: P. E. Kueser	1
Transducer Information Center Battelle Memorial Institute 505 King Avenue Columbus, Ohio 43201 Attention: G. L. McCann	1
Philco Corporation Aeronutronic Division Ford Road Newport Beach, California 92660 Attention: H. D. Lindhardt	1
Atomics International Liquid Metals Information Center P. O. Box 309 Canoga Park, California, 91304 Attention: R. W. Dickinson	1