NATIONAL BUREAU OF STANDARDS REPORT

8640

A STUDY OF VACUUM GAGES
FOR USE IN EVACUATING REFRIGERATING SYSTEMS

by

C. W. Phillips, S. D. Cole, and P. R. Achenbach

Report to
Office of the Chief of Engineers
Bureau of Yards and Docks
Engineering Division, U.S. Air Force

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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Mechanical Systems Section
Building Research Division

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ABSTRACT

Eight different instruments for indicating the absolute pressure of gases in a part or all of the range from 0.02 to 20 mm Hg were investigated for their suitability for field use in evacuating refrigerating systems during service operations. The test specimens included mercury McLeod gages, thermocouple gages, one electric resistance gage, and one absolute aneroid gage. The aneroid gage and one of the McLeod gages were calibrated against an NBS working standard and used thereafter as reference gages for comparison with the other test specimens. Dry nitrogen, dry air, laboratory air, saturated air, water vapor, and the refrigerant gases R11, R12 and R22 were used as test gases. It was found that the aneroid gage was probably best suited for field use when considering the factors of accuracy, applicability to all the test gases, ruggedness, simplicity, and ease of use. The McLeod gages, the electric resistance gage and some of the thermocouple gages were found to provide acceptable accuracy for limited ranges of pressure and for a narrower choice of gases in most cases.

1. INTRODUCTION

One principal method of removing water, air, or other deleterious or undesirable gases or vapors from hermetic refrigerating systems is the evacuation to low absolute pressures. Recommended evacuation pressures for this purpose are usually 100 microns Hg (0.1 mm Hg) absolute or lower. However, on the production lines for commercial refrigerating units, evacuation pressures may be lower than 10 microns Hg absolute and the systems for producing and measuring these pressures are frequently quite sophisticated.

For field evacuation of refrigerating systems to low absolute pressures, moderately-priced, portable gages capable of accurately measuring absolute pressures in the range from 100 microns Hg to 1 mm Hg (1000 microns Hg) or greater are needed to determine whether the prescribed low pressures have been achieved. Further, the ability of the several types of instruments to correctly indicate the absolute pressure of the system under evacuation when any of several gases or vapors are present must be known.

In this study, several types of gages, including aneroid, mercury McLeod, thermocouple, and electric resistance gages were investigated as indicators of low absolute pressures. The gages were compared when used with refrigerants R11, R12, and R22, nitrogen, dry air, laboratory air, air saturated with water vapor, and water vapor.

2. DESCRIPTION OF PRESSURE-INDICATING INSTRUMENTS

Eight different instruments were investigated, including 1 aneroid, 2 mercury McLeods, 4 thermocouple, and 1 electric resistance gage, as follows:

1. Wallace & Tiernan Absolute Pressure Indicator
2. Kinney Measuvac Mercury Manometer
3. Kontes Mercury Manometer
4. Arthur F. Smith Company Vacuum Gauge
5. NRC Equipment Corporation Vacuum Gauge
6. Hastings Vacuum Gauge, Model VT-6S
7. Hastings Vacuum Gauge, Model VT-4S
8. Consolidated Vacuum Company Pirani Vacuum Gauge

(1) The Wallace & Tiernan Absolute Pressure Indicator, Model FA-160, manufactured by Wallace & Tiernan, Inc., Belleville, New Jersey, was an aneroid diaphragm type absolute pressure indicator which measured the unknown pressure by comparison with the pressure in an evacuated capsule.

WALLACE & TIERNAN ABSOLUTE PRESSURE INDICATOR, MODEL FA-160

FIGURE 1

This eliminated the effect of barometric pressure changes. The absolute pressure was indicated directly by this gage without correction or adjustment in the range between 0.10 millimeter and 20 millimeters of mercury on a six-inch dial having more than 16 inches of scale length. As shown in Figure 1, the scale had 1-millimeter Hg numbered graduations each divided into 10 marked intervals of 0.1 millimeter Hg.

The mechanism consisted of a pressure sensitive element, lever system, pointer and dial, all housed in a suitable pressurized case. A metal capsule served as the pressure sensitive element which was connected to a geared sector through an actuating rod and flexible pivot. The sector engaged a pinion mounted on a pointer shaft. The shaft turned in bearings at the top and bottom. Backlash was prevented by a spring which provided uniform tension for all positions of the sector and pinion. The pressure sensitive element had a built-in stop which prevented damage to the mechanism from over-pressure. The instrument had a custom-calibrated dial over its full range intended to permit direct reading without reference to correction curves.

The gage was equipped with a Wallace & Tiernan Check Valve, FU-3229, screwed and sealed into the inlet connection. This valve was intended to provide a slow pressure change inside the gage if the measured pressure were suddenly increased, but offers little resistance when the pressure is decreased.

The instrument should be protected from severe vibration and located where the temperature will be as uniform as possible. To minimize hysteresis effect of the gage at the low end of the scale at the time of initial pulldown from atmospheric pressure, the manufacturer recommends an evacuation time of one-half to one hour.

The overall dimensions including vacuum connections are 8 1/2 inches in diameter and 4 1/2 ± 1/4 inch deep.

(2) The Kinney McLeod Gauge, Type T.D. 1, was manufactured by the Kinney Vacuum Division of the New York Air Brake Company, 3529 Washington Street, Boston 30, Mass. It was a mercury manometer with two separate closed end capillaries having different compression ratios enabling pressure measurements to be made in the range from 150 mm to 2 mm Hg on one graduated tube and 2000 microns to 1 micron Hg on the other graduated tube. The approximate scale lengths for the 2 to 150 mm scale and the .001 to 2 mm scale were 4 inches and 3 3/8 inches, respectively. (See Figure 2.) The pivoted handle on the right, when lowered, raised a rubber diaphragm which formed the bottom of the mercury container, forcing mercury up into the two closed-end glass capillary tubes and one open glass tube, on the right, which connects the system under pressure measurement to the mercury container in the gage.

KINNEY "MEASUVAC" HG MC LEOD GAGE
FIGURE 2

The amount of mercury used in the gage was critical between 16 1/4 and 16 3/4 cc. Too little mercury would result in inability to raise the mercury level to the set line on the open glass tube; too much mercury would result in permanent trapping of air in the high pressure capillary tubes. The latter error could be detected by comparing the readings on both pressure capillaries at the 2 mm Hg pressure level.

The system pressure to be measured was connected to the gage at the top through a 1/4-inch metal tube held against the right-hand open glass tube by means of a knurled nut washer and O-ring, with a flexible connection extending from the exposed end of the 1/4-inch tube to the system.

Operation of the gage at atmospheric pressure should generally be avoided as depression of the handle may force mercury out of the open end tube, disturbing the critical amount of mercury in the gage.

When taking a reading, the handle should be depressed steadily. Too quick or too jerky a movement may shoot the mercury up into the closed-end tubes irrespective of compression and give an erroneous reading. A steady operation of the handle will force the mercury up the glass tubes and when the mercury in the right-hand glass tube reaches the set mark, a reading can be taken from the mercury level in whichever of the two closed-end glass tubes indicates on scale at the time. A steady release of the handle clears the tubes of mercury, making the gage ready for another reading.

The overall size of the gage with handle and legs, as used for bench mounting, was 10 in. wide by 8 in. deep by 14 in. high, exclusive of the 1/4-in. connection tube.

McLeod gages cannot be used to reliably measure the pressure of gases (vapors) if the pressure in the compression tube of the gage at the time of measurement approaches the condensing pressure of the gas or of one constituent of a mixture of gases. For this reason, the Kinney McLeod gage was not used as a reference gage in tests with saturated air or water vapor. The pressure in the measuring tube of a mercury McLeod gage is equal to the system pressure plus the mercury head required to compress the sample. At system pressures of 2, 1, and 0.1 mm Hg, respectively, the mercury heads in the 0 to 2 mm Hg tube of the Kinney McLeod gage required to compress the sample are 89, 64, and 23 mm which would produce pressures on the sample of 91, 65, and 23 mm Hg. From Table 1 it can be seen that, of the gases tested in this investigation, water vapor is the one which approaches or would exceed its condensing pressure in the 0 to 2 mm Hg range of the Kinney McLeod gage at room temperature.

TABLE 1

Condensing Pressure of Sample Gases

Gas	Critical Temp., °F	Condensing Pressure at 75°F, mm Hg
Water	706	22.2
R11	388	765
R12	234	4740
R22	205	7660
Air	-221	None, above critical Temp.
Nitrogen	-233	" " " "

(3) The Kontes Mercury Manometer was a McLeod gage manufactured by the Kontes Glass Company, Vineland, New Jersey, and is shown in Figure 3.

The gage used a column of mercury as a piston to compress a certain known volume of gas to a smaller known volume. Because the mathematical product of "pressure times volume" is a constant, or PV = P'V', the pressure of this sample of gas can be indicated on a suitable scale. In this instrument, the scale covered the range from 0 to 1000 microns Hg, and was about 4 inches long. The relationship, PV = P'V', remaining constant depends upon the temperature remaining constant and upon the gas sample being an ideal gas. Condensable vapor in the gas sample will cause the indicated pressure to be less than the correct pressure. This was discussed in more detail in description of the Kinney McLeod gage.

To obtain a pressure reading, the mercury-containing portion of the Kontes gage is rotated more than 90 degrees clockwise from the position shown in Figure 3. The rotating hub is directly behind the larger bulb in the center of the tubing assembly. The pressure to be measured is connected at the back of the instrument and a connecting tube runs through the hub into the larger bulb. In the rotated position the mercury drains into the right hand bulb. The system pressure to be measured can then communicate with the scale tube which is closed at the top end. Returning the gage to the position shown in Figure 3 allows mercury to flow up into the two left-hand tubes, compressing the gas in the scale tube and overflowing the other, imposing a fixed mercury head on the gas compressed in the scale tube. The tube connecting the gage to the system under measurement must be flexible to permit rotating the gage assembly.

The overall size of the instrument, including gage and mounting stand, was 10 inches high, 6 1/2 inches wide, and 6 inches deep when the gage is vertical. When the gage is rotated to a horizontal position, the instrument measures 8 1/2 inches high, 9 inches wide, and 6 inches deep.

KONTES HG MC LEOD GAGE
FIGURE 3

Thermocouple-type Instruments

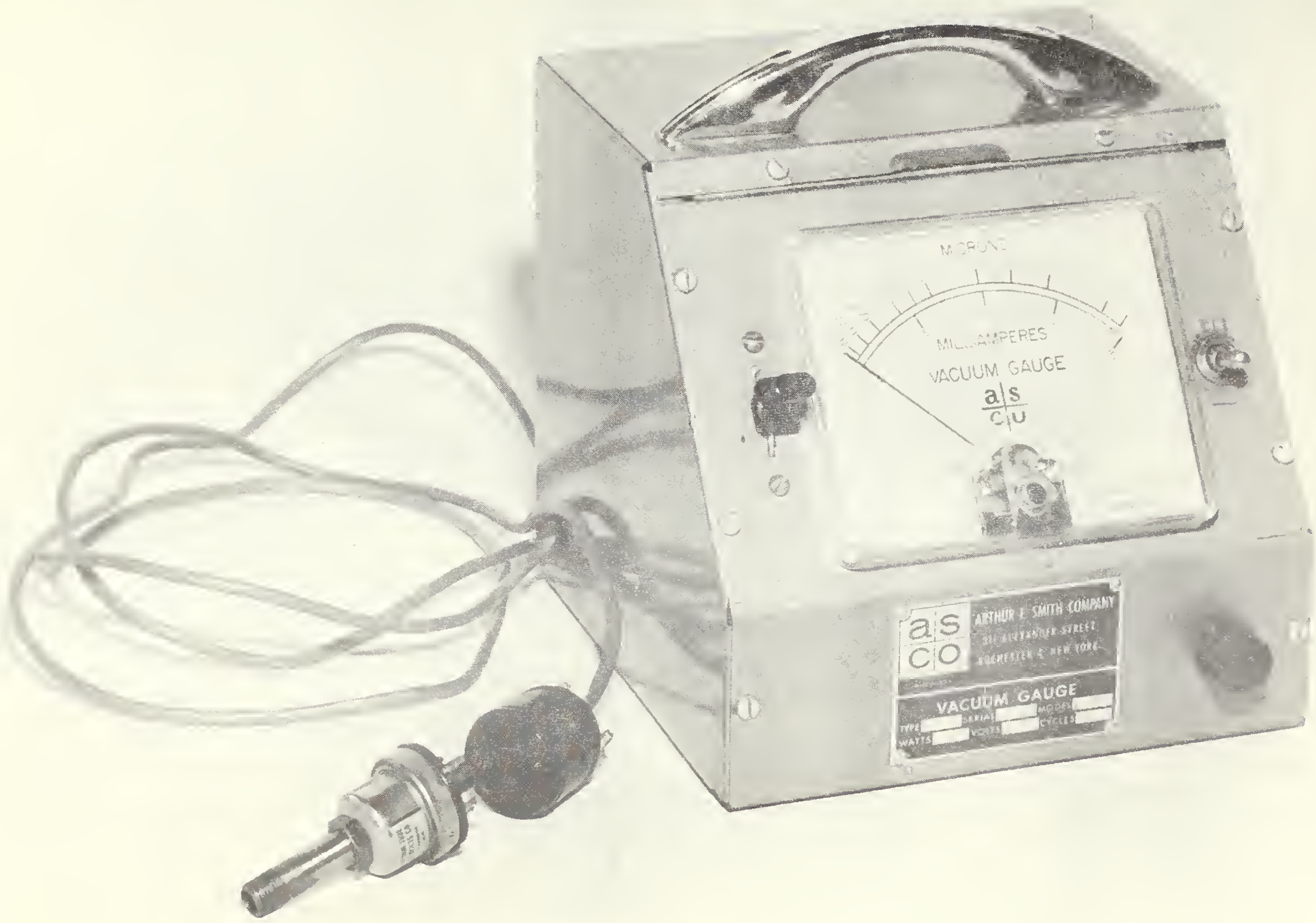
The four instruments described next used the heated-thermocouple principle for determining low absolute pressures. In this type of instrument, the change of temperature of an electrically-heated filament in the cavity of the gage tube is measured by a thermocouple. This change of temperature is caused by the change in heat transfer through the gas caused by the change of pressure in the cavity and produces a change in electric current flow through a sensitive milliammeter in the thermocouple circuit. The heater current is held constant, and the temperature of the thermocouple is in part, then, a function of the heat conduction capacity of the gas in the gage tube or cavity. In general, the conductivity[1/] of a gas becomes almost constant above about 1 mm Hg absolute pressure so that most instruments lose sensitivity above this pressure. As the pressure is reduced, the temperature of the thermocouple increases. The proportion of heat lost from the heated wire by radiation and stem conduction increases and that lost through gas conduction decreases. For absolute pressures below about 10^{-3} mm Hg, most thermocouple gages are not practical because a very small proportion of the total heat transfer from the thermocouple is caused by conduction through the gas. The reference junction for the thermocouple on the heated wire is usually at the temperature of the case of the gage tube. Because different gases and vapors have different conductivities and different "accommodation coefficients", a single calibration is not applicable for all gases. The accommodation coefficient is an index of the ability of a gas to remove heat from a surface. Most thermocouple gages for refrigeration evacuation work are calibrated with dry air as the reference gas.

(4) The ASCO battery-operated thermocouple vacuum gage, shown in Figure 4, was a Type 1, Model 1013, manufactured by the Arthur F. Smith Co., 311 Alexander Street, Rochester 4, New York. The gage operated with a gage tube, Type VTP6343, manufactured by the Vacuum Tube Products Co., Inc., 506 South Cleveland Street, Oceanside, California.

The gage provided a milliampere scale and current adjustment knob to set the heater current to the milliampere rating marked on the thermocouple gage tube. The gage tube is in the lower left corner of Figure 4.

The numbered portion of the measurement range indicated on the scale extended from zero to 1000 microns Hg absolute pressure. The non-uniformly graduated scale was about 3 1/2 inches long with about 80% of the scale length covering the range from zero to 200 microns. A 1-1/2-volt flashlight battery may be used for short periods of use, but a Mallory RM-42R battery is recommended by the manufacturer for extended battery life.

[1/] Richard B. Lawrence, A Survey of Gages for the Measurement of Low Absolute Gas Pressures, Chemical Engineering Progress, Vol. 50, No. 3, March 1954.



ASCO THERMOCOUPLE GAGE
FIGURE 4

The instrument was 6 1/2 inches high, 7 inches wide, and 7 1/4 inches deep. The top 5 inches of the front face was sloped so that the top was but 4 1/2 inches deep.

To operate, the gage tube with six-foot lead is connected to the vacuum system and the off-on switch turned on. After setting the heater current to the proper milliampere rating for the particular gage tube, the instrument is ready for use.

(5) The NRC Vacuum Gauge, manufactured by the NRC Equipment Corporation, a subsidiary of National Research Corporation, Newton Highlands 61, Massachusetts, consisted of a Type 701 Vacuum Gauge Control and a Type 501 Gauge Tube. This apparatus, which operated on 115 V, AC, is shown in Figure 5. The thermocouple gage control incorporated a vacuum indicating device for indicating pressures over a continuous range from zero to 1000 microns Hg absolute pressure. These pressures could be read directly on a microammeter which was calibrated in microns Hg on a 2-1/4-inch non-uniformly graduated scale with 2 inches of the scale length covering the range from zero to 200 microns Hg. As shown in Figure 5, the control unit provided an A.C. ammeter (on left) for use in setting the heater current. The knob between the two meters was used to adjust the heater current. The right-hand meter indicated the pressure.

The unit used a welded metal thermocouple gage tube which enclosed the heater and thermocouple elements. A calibration curve in microns Hg per microampere characteristic of the gage's non-linear response was furnished on the gage tube label. Each gage tube was individually calibrated and the heater filament current was stamped on the tube base. The gage was reported to be capable of operation without damage at atmospheric pressure.

The physical specifications of the unit were:

Size - - - Length 11", Height 7 1/2", Depth 8 1/4"
Weight - - - 12 lb
Power Cord - 6 ft long, 115 volt with standard AC plug
Gage Cord - 6 ft long, 4-wire lead, octal plug

The operational specifications of the control unit and thermocouple gage tube were:

Power supply - 115 volt, single phase, 50/60 cycles
Filament supply:
Maximum, 0.9 amperes
Minimum, 0.56 amperes
Operational, 0.60 to 0.68 amperes adjustable

NRC THERMOCOUPLE GAGE, TYPE 701
FIGURE 5

Filament current:

0.6 amperes plus hundredths of an ampere corresponding to calibration number stamped on the gage.
Maximum filament current, 1.0 amperes.
Filament resistance, 0.2 ohms (approximate).
Thermocouple output, 0 - 14 millivolts maximum.
Indicating range, 1 - 1000 microns Hg absolute in dry air.

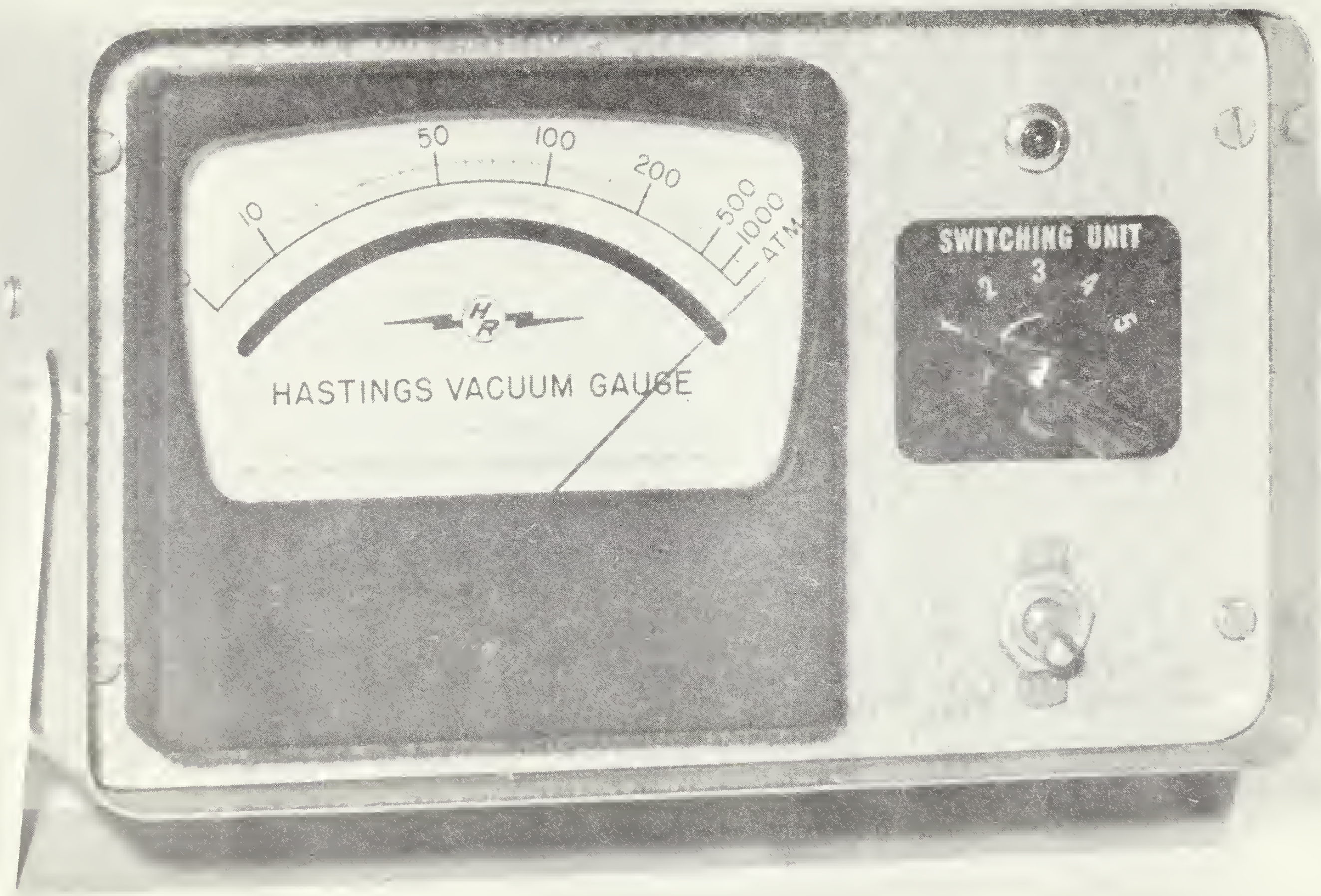
(6 & 7) Two thermocouple-type Hastings Vacuum Gauges, Model VT-6S and Model VT-4S were investigated and are shown, respectively, in Figures 6 and 7. They were manufactured by Hastings-Raydist, Inc., Hampton, Virginia, and identified as thermopile gage controls.

The two models were similar except for the working range of measurement. Model VT-6S had a principal indicating range of 0 - 1000 microns Hg, and Model VT-4S had a principal range of 0 - 20 millimeters Hg. The pressures were indicated directly on the microammeters of the two gages graduated non-uniformly in microns Hg and in millimeters Hg above zero absolute pressure, respectively. Each gage was equipped with a five-position selector switch for reading of any one of five gage tubes. Figure 7 shows the five gage tube leads, electric power cord, and one of the five type DV-4DM gage tubes furnished with the Model VT-4S gage. Type DV-6M gage tubes were furnished for use with the Model VT-6S gage.

According to the literature furnished with the gages, the gage tubes for each range were matched and interchangeable without calibration adjustment. They had built-in compensation for temperature and rate of change of temperature. It was stated that extension cables could be added between the gage tube and the instrument with little or no effect on calibration, thus extensions for remote indications could be added, if desired. The gage tubes were nickel plated and connected to the vacuum system by means of a 1/8" NPT male pipe thread. The heater current input was preset at the factory and remained the same for all gage tubes used with a particular instrument. No external means for adjusting the heater current was provided and the gages did not have a means for indicating the heater current.

The instruments were designed to operate on 115 volt, AC power of any frequency and were provided with a three-wire 8-ft power cable. Power requirement was stated as less than one watt.

The overall size of the Hastings Vacuum Gauges without gage tubes and leads was 7 3/4 in. long by 4 3/4 in. high by 4 1/2 in. deep, with a removable carrying handle.



HASTINGS THERMOCOUPLE GAGE, MODEL VT-6S
FIGURE 6

HASTINGS THERMOCOUPLE GAGE, MODEL VT-4S
FIGURE 7

(8) The Pirani Vacuum Gauge Type GP-110 was manufactured by the Consolidated Vacuum Company, Rochester 3, New York, and is shown in Figure 8. The operation of a Pirani-type gage, which is a thermal conductivity vacuum gage, was based upon the changes in the temperature (and resistance) of a heated filament. This temperature change was partly a function of the surrounding gas pressure. Resistance was measured with a conventional Wheatstone bridge circuit which was made insensitive to ambient temperature changes by use of a compensating tube in one arm of the bridge. For the gage under test, a sensitive microammeter graduated in pressure units from zero to 50 microns Hg and zero to 2000 microns Hg on two scales was used to measure the unbalance of the bridge. The non-uniformly graduated scale length was about 3 5/8 inches.

According to literature furnished with the gage, the power supply for the bridge consisted of a step-down transformer, a full-wave selenium rectifier, and an automatic current regulator tube which developed a constant voltage drop across the bridge voltage potentiometer.

The metal sensing tube was 7 inches long overall: 5 5/8 inches of the tube was 1 1/4 inches in diameter, and 1 3/8 inches was a 1/2-inch tube to receive flexible tubing for connection to the system. The tube was calibrated for use in ambient temperature between 59°F and 95°F, and should be recalibrated for use in temperatures outside of the designated range. The tube was connected to the gage cabinet with a 10-foot length of cord. The cabinet was 6 inches in height, 10 3/4 inches in width, and 5 5/16 inches in depth, and its weight was 10 lb.

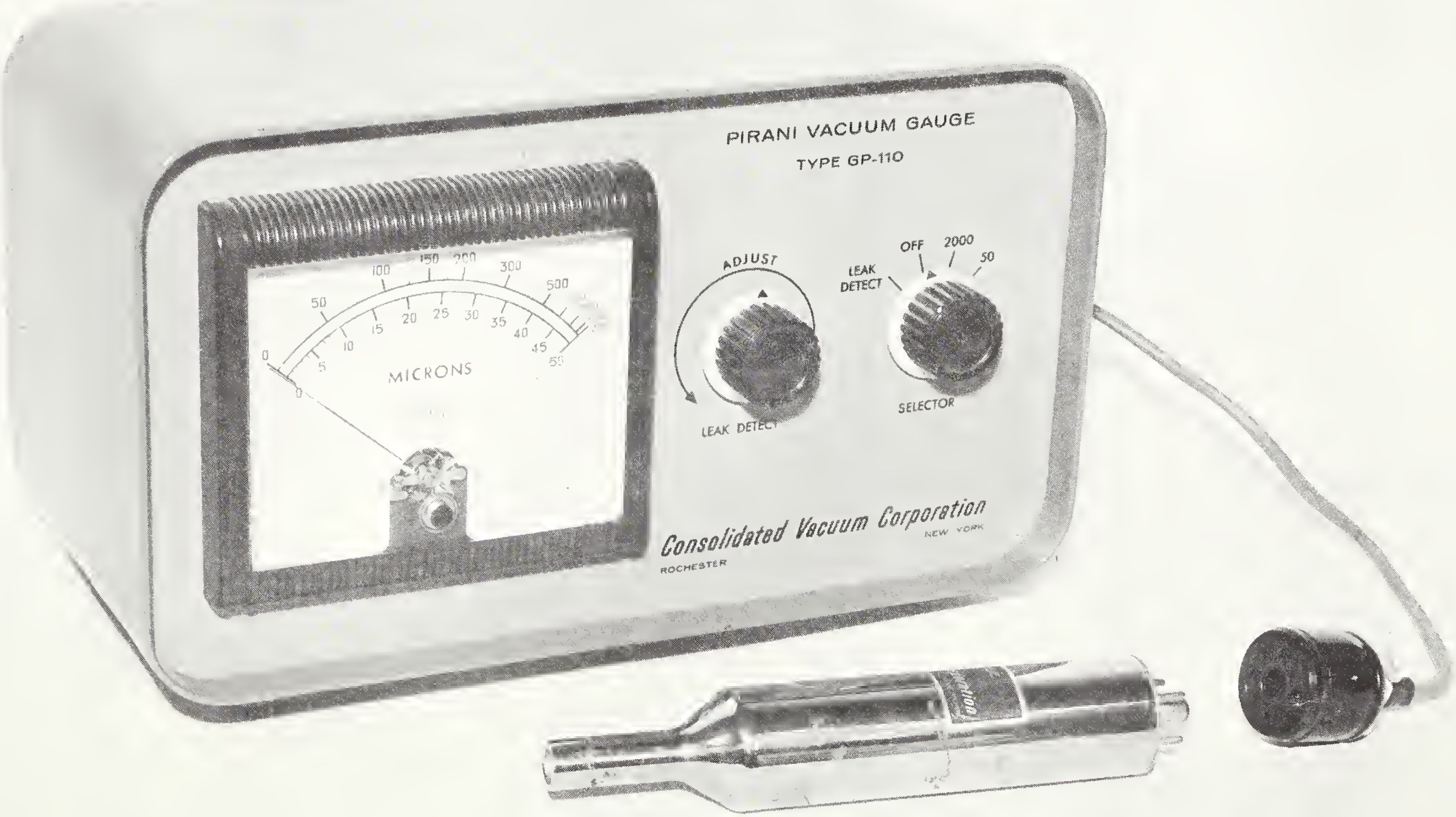
Gage Tubes

Figure 9 shows the shape, relative size, and means for pressure and electrical connections for, left to right,

1. CVC Pirani resistance gage tube
2. NRC Thermocouple gage tube
3. ASCO Thermocouple gage tube
4.)
5.) Hastings Thermocouple gage tubes of two types. The tubes of the two different ranges were distinguished from each other by means of different colored marking: blue for the type DV-4DM (principal range 0 to 20 mm Hg) and brown for the type DV-6M (principal range 0 to 1000 microns Hg).

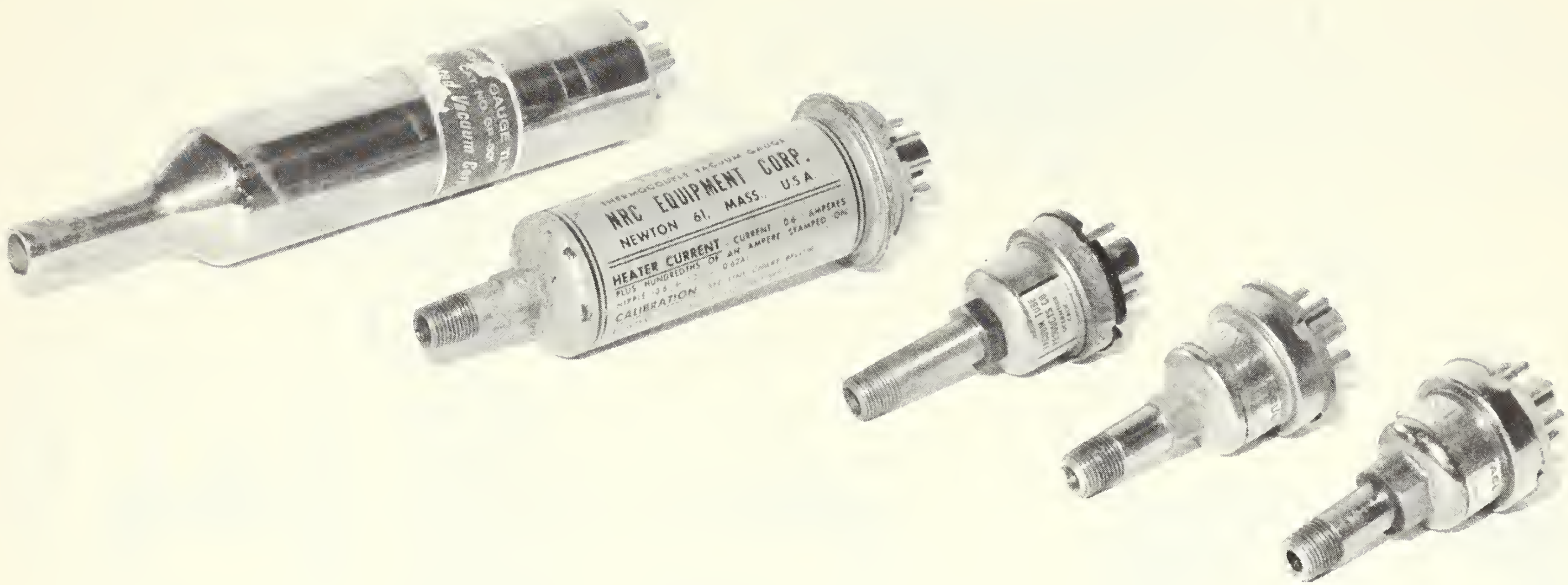
Gage Scales

Figures 10 and 11 are actual-size photographic reproductions of the non-uniform graduated scales for the McLeod, Thermocouple, and Pirani-type gages investigated. It will be noted that some scales are difficult to read because the scale intervals are not uniform in either length or value for even the principal working portion of the full scale range. Figure 12 is an actual-size photographic reproduction of the scale of the Wallace & Tiernan aneroid gage.



PIRANI GAGE, TYPE GP-110

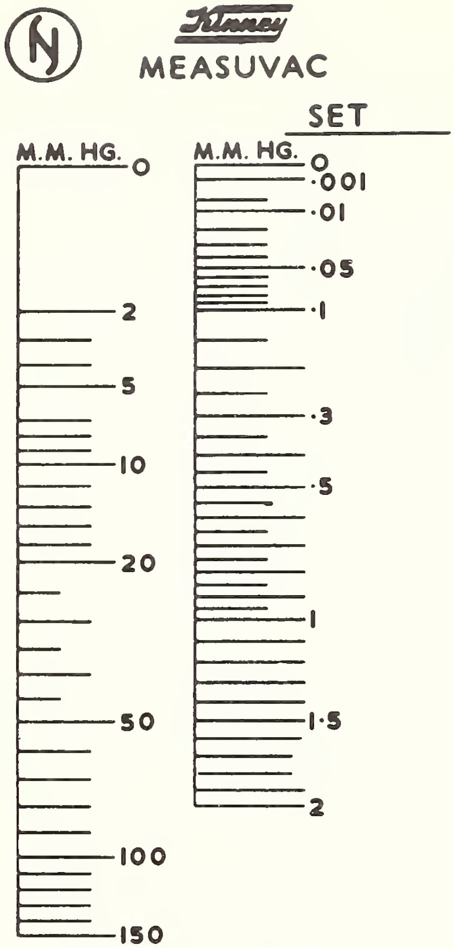
FIGURE 8



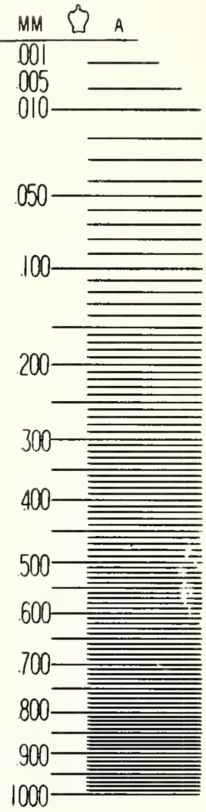
VACUUM GAGE TUBES:

1. CVC PIRANI
2. NRC THERMOCOUPLE
3. ASCO THERMOCOUPLE
4.) HASTINGS
5.) THERMOCOUPLE (2 TYPES)

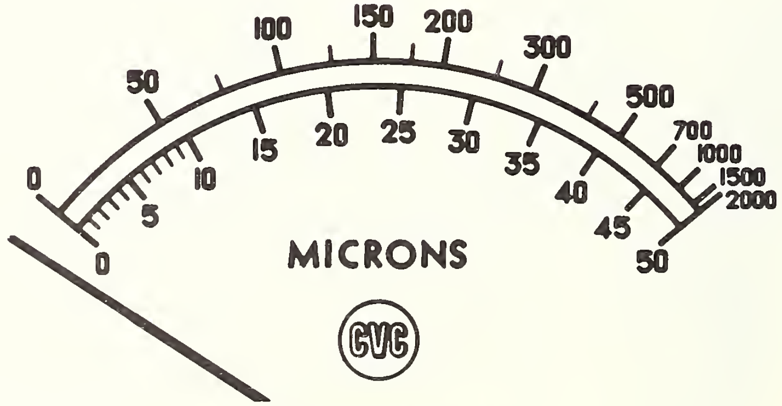
FIGURE 9



KINNEY MC LEOD GAGE



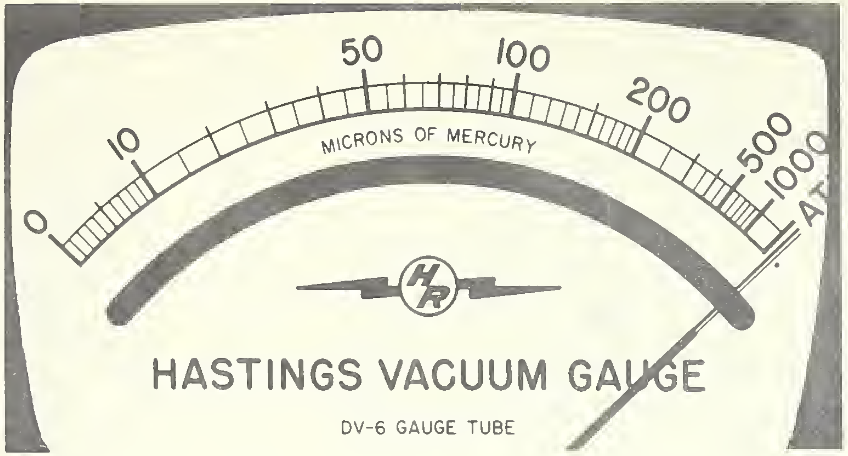
KONTES MC LEOD GAGE



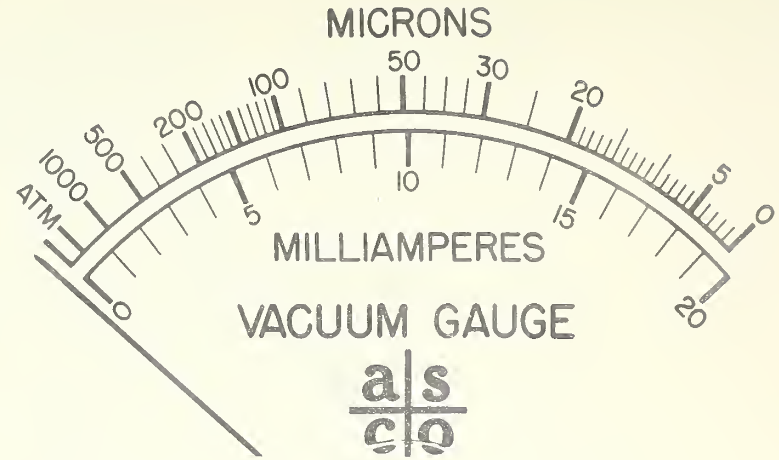
CVC PIRANI GAGE

SCALES, ACTUAL SIZE

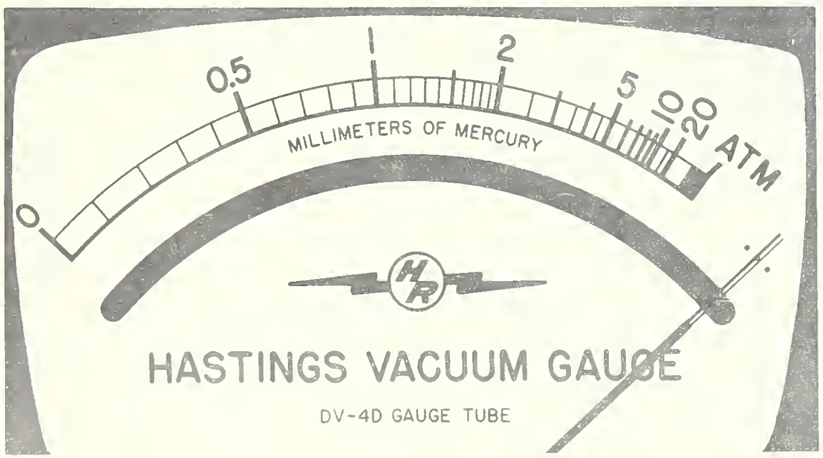
FIGURE 10



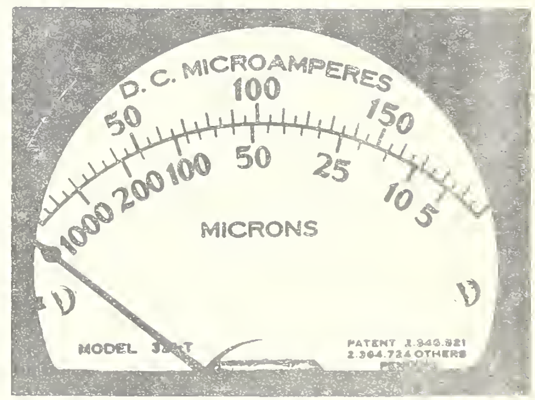
HASTINGS (MODEL VT-6S)



ASCO



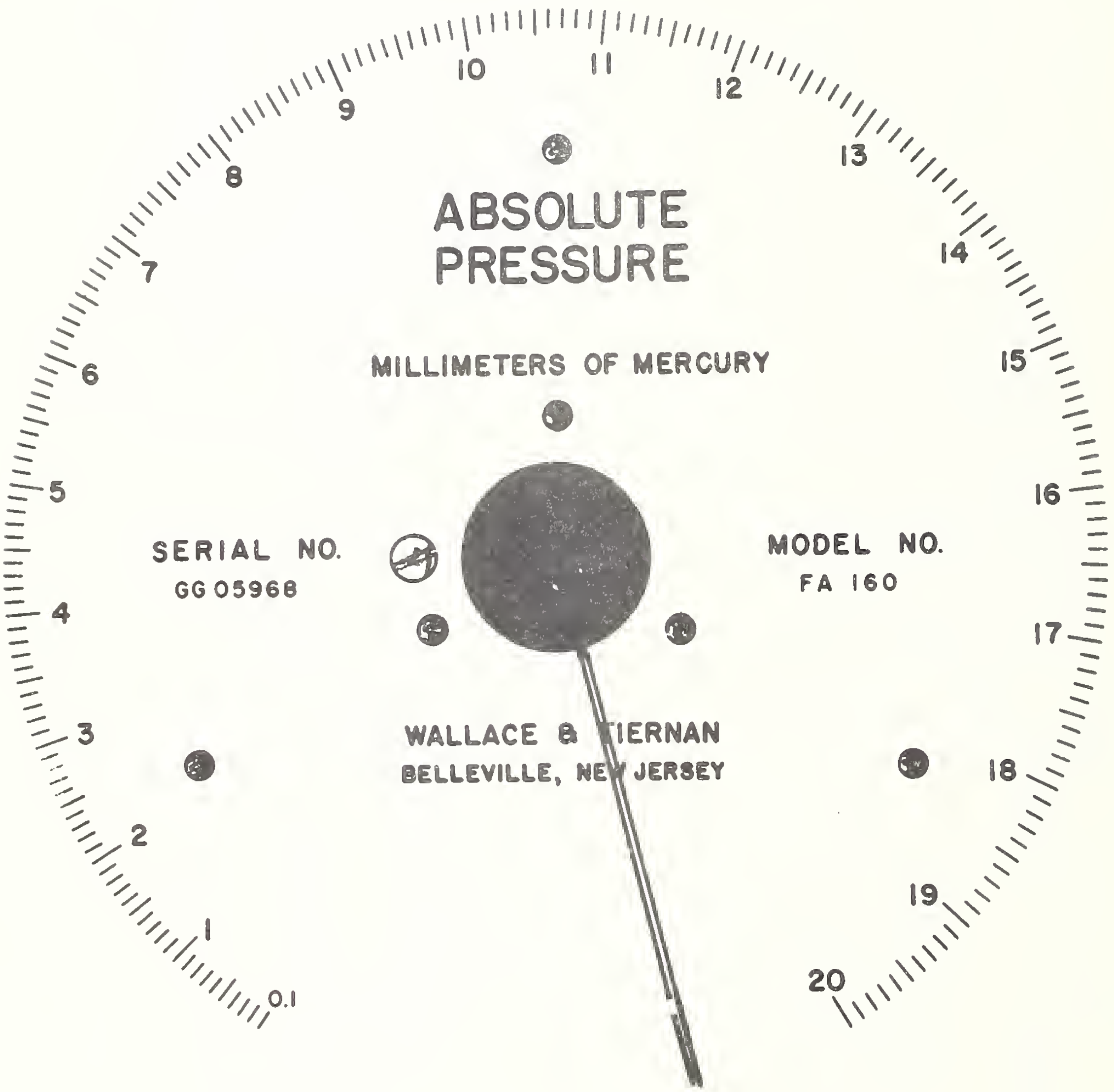
HASTINGS (MODEL VT-4S)



NRC

SCALES, ACTUAL SIZE, OF FOUR THERMOCOUPLE-TYPE GAGES

FIGURE 11



WALLACE & TIERNAN ANEROID GAGE SCALE, ACTUAL SIZE

FIGURE 12

3. TEST APPARATUS

The test apparatus was designed to provide means for comparing the readings obtained from the various gages under test with calibrated reference gages, under either increasing or decreasing pressure, in the range from below 0.1 mm Hg to 20 mm Hg, and with several different gases. The apparatus consisted essentially of a pipe circuit incorporating a vacuum pump, a nitrogen cold trap, a gage manifold, two gas tanks, a chemical dryer and sources of the various test gases. Figure 13 is a schematic drawing of the test apparatus, with the various parts connected with copper tube and rubber tubing joints.

The vacuum pump was a Welch Duo-Seal Vacuum Pump manufactured by the Welch Scientific Company, 1515 Sedgwick Street, Chicago 10, Illinois; Model 1405-B, 525 RPM, 115 V, 60 cycle, AC, 1/2 HP motor. A clutch at the motor shaft provided for easy starting. The pump was a two-stage unit with a rated capacity of 58 liters per min. at 1 micron absolute pressure at the inlet and an end point of 0.1 micron. A ballast valve was provided for the removal of gases from a system without excessive contamination of the pump oil.

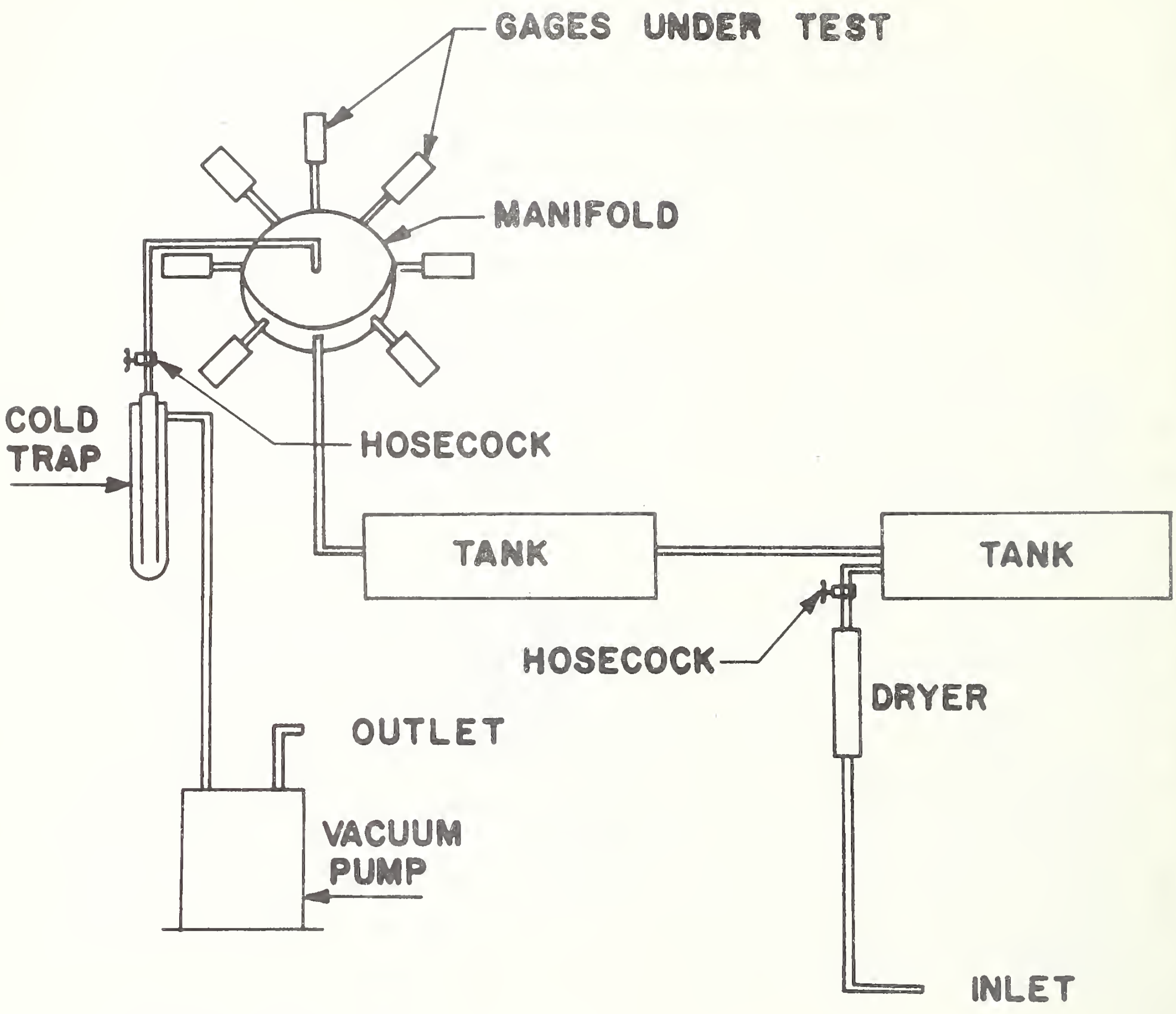
The cold trap was of glass and was refrigerated by liquid nitrogen in a one-quart size Dewar flask. The height of the glass trap was 16 inches and the inlet and outlet connections were 3/4 inches.

Figure 14 is a slightly enlarged view of the manifold to which the test gages were attached, as indicated in Figure 13. The body of the manifold consisted of a 1-inch length of 2-inch copper pipe with square copper plates hard-soldered on the ends. Eight 1 1/2 inch-long pieces of 3/8-inch copper tube were soldered with equal spacing to the circular surface of the manifold for use in connecting the test gages, and one section of 3/8-inch tube 3 1/2 inches long was hard-soldered to one of the flat surfaces, exactly at the center of the 2-inch pipe, for connection to the vacuum pump. The corners of the bottom flat plate were drilled for rigid mounting in a fixed position.

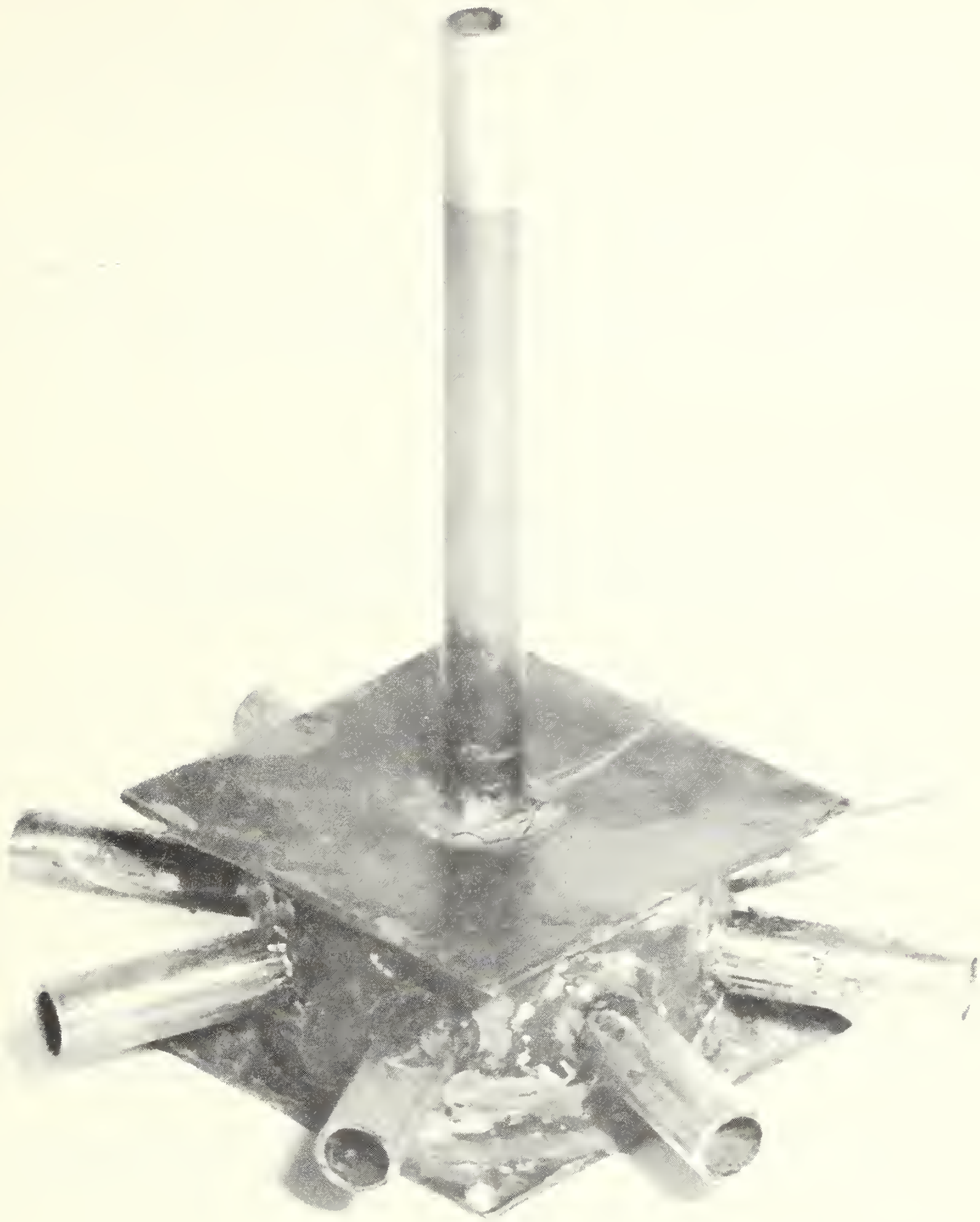
The two tanks were 2-foot-long sections of 5-inch copper pipe and were connected with sections of 1-inch copper pipe with rubber tube joints. The tanks provided a volume element for the system.

The chemical dryer at the inlet opening removed unwanted moisture from gases entering the system for some tests. Other tests required the addition of water or vapor to the entering gases.

A six-foot diameter rubber balloon was used to hold the various test gases, taken from high pressure cylinders, at atmospheric pressure before and during introduction into the system. The balloon was completely evacuated before being filled to full size by the gas being used during a particular investigation.



SCHEMATIC ARRANGEMENT OF TEST APPARATUS
FIGURE 13



GAGE TEST MANIFOLD
FIGURE 14

Reference Gages for Test

The Wallace & Tiernan aneroid gage (Figure 1) was used as the reference gage in the comparison tests for the pressure range from 20 mm to 0.2 mm Hg absolute. The Kinney McLeod gage (Figure 2) was used as the reference gage for the pressure range from 0.2 mm to .001 mm Hg absolute since this was below the calibrated range of the Wallace & Tiernan aneroid gage. The McLeod gage was not used for reference purposes when tests with saturated air or water vapor were made.

These two reference gages were calibrated by the Pressure and Vacuum Section of the National Bureau of Standards. The reference gages were calibrated by means of oil and mercury hook-type differential micromanometers against an absolute pressure of approximately 1 micron (.001 mm) Hg. The accuracy of the calibration system was within 5 microns (.005 mm) Hg.

4. TEST PROCEDURE

In general, the test procedure was designed to compare the pressure indications of the various test gages with one or both of the calibrated reference gages over an absolute pressure range from about 0.1 mm Hg (100 microns Hg) to 20 mm Hg using various gases in the test system.

The gases used in the test series included:

1. Nitrogen
2. Dry air
3. Laboratory air (approx. 50% R.H.)
4. Air saturated with water vapor
5. Water vapor
6. R11
7. R12
8. R22

The test apparatus was assembled as illustrated schematically in Figure 13, when used with all gases except water vapor, laboratory air, and saturated air. For these three fluids the dryer was removed.

Prior to making comparative pressure observations with each gas, the system was evacuated to as low an absolute pressure as the vacuum pump could develop and then filled to atmospheric pressure with the particular gas being used, except for water vapor in which case the pressure was raised to 20 mm Hg. This cycle was repeated from four to six times with each gas.

With the hosecock downstream from the dryer closed off and the system filled at atmospheric pressure with the test gas, evacuation by the pump was continued until the aneroid reference gage indicated a pressure between 19 mm and 20 mm Hg absolute. At this time the hosecock upstream of the cold trap was closed, with the pump operating, and the current adjusted for the two thermocouple gages which required manual adjustment. The indicated pressures on all gages were read and recorded at this initial condition.

A routine procedure was established of opening the hosecock, evacuating the system by an increment of pressure, closing the hosecock and recording the values indicated by all gages, until the system was evacuated to the limit of the pump.

The absolute pressure range from 20 mm to 0.1 mm was arbitrarily divided into 20 intervals for comparative readings, with 5 intervals in the range from 1 mm to less than 0.1 mm Hg, because some of the electronic gages were designed for use principally in this range.

At the conclusion of the evacuation process, the vacuum pump was stopped, the outlet hosecock was closed and the inlet hosecock was repeatedly opened and closed, such that various levels of pressure occurred in the system in about 20 intervals similar to those observed when the system was being evacuated.

When the tests with dry air, nitrogen, refrigerants R11, R12 and R22 were conducted, the gas entered the system at the inlet end and passed through a dryer to remove water vapor before entering the first volume tank. For the test with laboratory air, the ambient room air was introduced into the system without passing through the dryer.

Water-saturated air was prepared for test by bubbling laboratory air through a five-gallon container filled about three quarters full with water at room temperature. The air inlet tube extended to the bottom of the container and the entrance to the air outlet tube was located at the top. The humidified air was drawn through the test system until the cold trap was nearly stopped with ice; the system was then isolated from the cold trap by stopping the pump and closing the hosecock; and a second cold trap inserted in place of the frozen one. Following this purging operation, the test readings were made at various pressure levels in the system.

For the tests with water vapor, the same five-gallon container was used as for the saturated air tests, but with the water heated to about 131°F and with the air inlet tube to the container closed. The test system was alternately evacuated and allowed to fill with water vapor from the heated container to about 20 mm Hg absolute pressure a few times, prior to the test observations.

5. TEST RESULTS AND DISCUSSION

Comparative results of the tests of one aneroid gage, two McLeod gages, four thermocouple gages, and one Pirani gage are shown in Figures 15 through 40. For most of the tests either the Wallace & Tiernan aneroid gage (for tests in the absolute pressure range from 20 mm Hg to 0.2 mm Hg) or the Kinney McLeod gage (for tests below 0.2 mm Hg) was used as a reference gage. These two gages were calibrated against an

NBS working standard as described under the Test Apparatus Section of this report. The results of the calibrations of the two reference gages by the NBS Pressure Measurement Section are shown in Tables 2 and 3, and in Figures 15 and 16. The calibration data in these two figures for the Wallace & Tiernan gage were plotted for decreasing pressure only since all pressure comparisons were made under decreasing pressure conditions during the tests.

TABLE 2

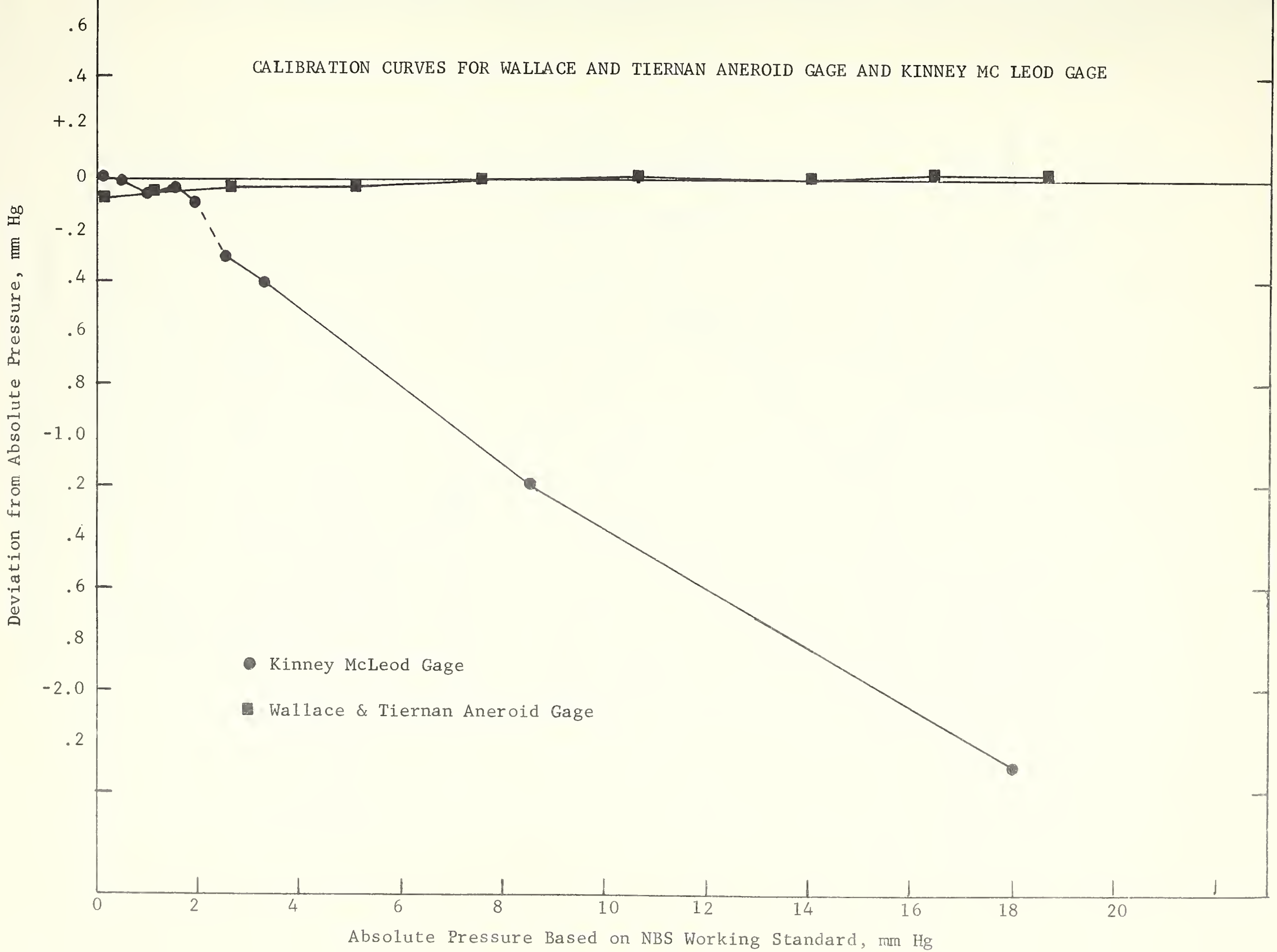
Calibration of Wallace & Tiernan Aneroid Gage

Increasing Pressure		Decreasing Pressure	
Average Reading mm Hg	Deviation from NBS Working Standard mm Hg	Average Reading mm Hg	Deviation from NBS Working Standard mm Hg
0.32	-0.12	18.62	+0.02
0.92	-0.11	16.38	+0.02
3.92	-0.11	14.03	0.00
7.90	-0.09	10.59	+0.01
13.22	-0.07	7.58	0.00
16.50	-0.06	5.10	-0.03
19.00	-0.06	2.64	-0.03
19.92	-0.04	1.13	-0.06
20.00	0.00	0.16	-0.08

TABLE 3

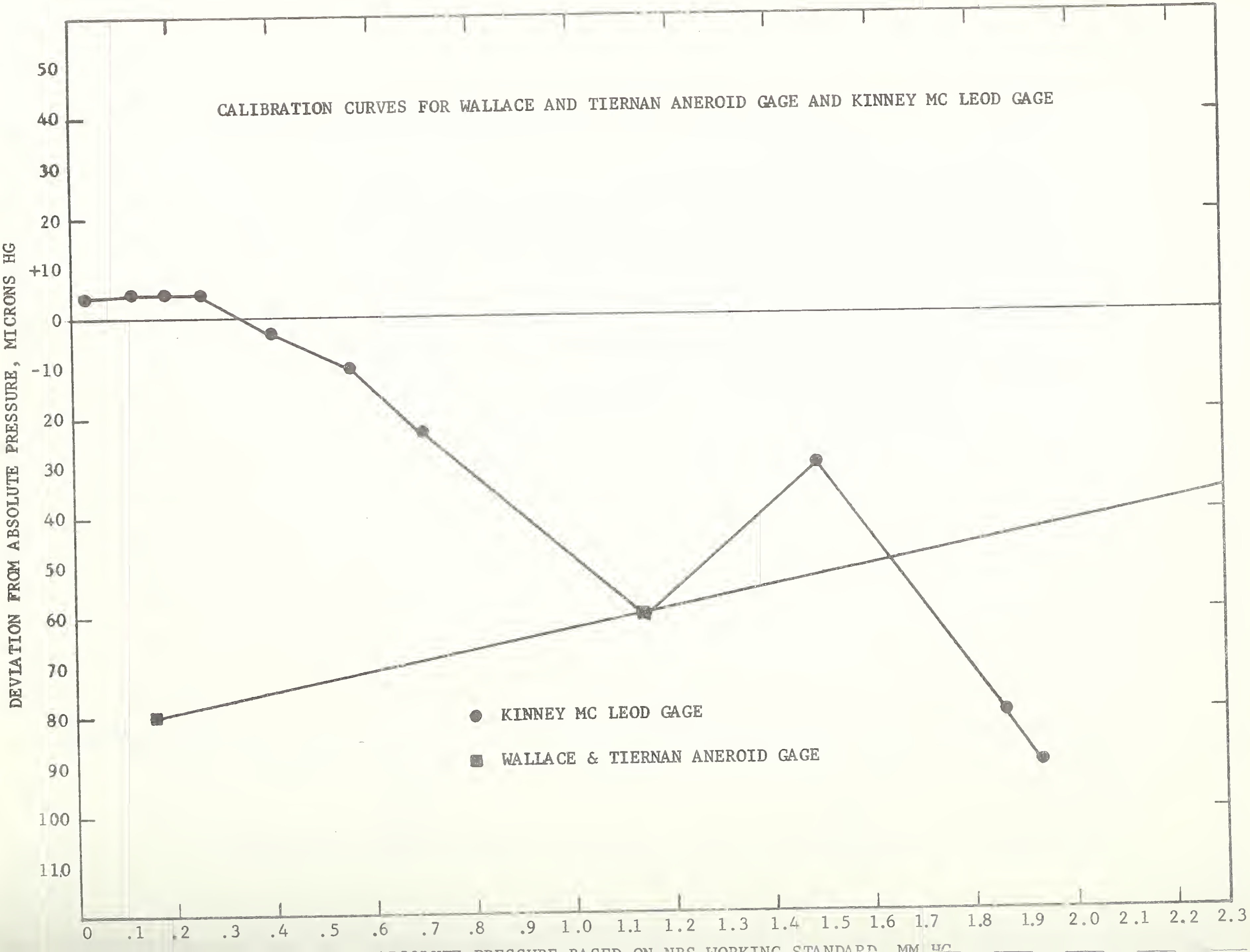
Calibration of Kinney McLeod Gage

0 to 2 mm Hg Range		0 to 150 mm Hg Range	
Reading mm Hg	Deviation from NBS Working Standard mm Hg	Reading mm Hg	Deviation from NBS Working Standard mm Hg
0.026	+0.004	1.9	-0.1
0.120	+0.005	2.5	-0.3
0.190	+0.005	3.3	-0.4
0.260	+0.005	8.5	-1.2
0.400	-0.003	18.0	-2.3
0.560	-0.010		
0.700	-0.023	38.0	-2.3
1.14	-0.06	80.0	-3.5
1.49	-0.03		
1.86	-0.08		
1.93	-0.09		



CALIBRATION CURVES FOR WALLACE AND TIERNAN ANEROID GAGE AND KINNEY MC LEOD GAGE
.6
.4
+.2
0
-.2
.4
.6
.8
-1.0
.2
.4
.6
.8
-2.0
.2
Deviation from Absolute Pressure, mm Hg
Kinney McLeod Gage
Wallace & Tiernan Aneroid Gage
0
2
4
6
8
10
12
14
16
18
20
Absolute Pressure Based on NBS Working Standard, mm Hg

FIGURE 15


CALIBRATION CURVES FOR WALLACE AND TIERNAN ANEROID GAGE AND KINNEY MC LEOD GAGE
DEVIATION FROM ABSOLUTE PRESSURE, MICRONS HG
50
40
30
20
+10
0
-10
20
30
40
50
60
70
80
90
100
110
KINNEY MC LEOD GAGE
WALLACE & TIERNAN ANEROID GAGE
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3

During the tests, all the gages were connected to the system for all test runs, but, because the indicating ranges of the gages differed, some tests did not produce values for all of the gages investigated. The test system was evacuated to the limit of the vacuum pump for each test, but for the tests with saturated air and water vapor, the identification of the reference pressure was limited to the calibrated scale range of the Wallace & Tiernan aneroid gage, i.e. from 0.1 mm to 20 mm Hg. Pressures below 0.1 mm Hg were indicated by the other gages and the calibrated Kinney McLeod gage was used as a reference for absolute pressures lower than about 0.15 mm Hg (150 microns) for all of the test gases except saturated air and water vapor.

Table 4 lists the principal or working portion of the scale range, and full scale range (see Figures 10-12) of the seven gages.

TABLE 4

Absolute Pressure Scale Ranges of Test Gages

Gage	Type	Working Scale	Full Scale
Wallace & Tiernan	Aneroid	0.1 to 20 mm Hg	0.1 to 20 mm Hg
Kinney	McLeod	0 to 2 mm Hg	0 to 2 mm Hg
		0 to 150 mm Hg	0 to 150 mm Hg
Kontes	McLeod	0 to 1000 microns Hg	0 to 1000 microns Hg
ASCO	Thermocouple	0 to 1000 microns Hg	0 to Atm
NRC	Thermocouple	0 to 1000 microns Hg	0 to >1000 microns Hg
Hastings	Thermocouple (Mod. VT-6S)	0 to 1000 microns Hg	0 to Atm
Hastings	Thermocouple (Mod. VT-4S)	0 to 20 mm Hg	0 to Atm
CVC	Pirani	0 to 50 microns Hg	0 to 50 microns Hg
		0 to 2000 microns Hg	0 to 2000 microns Hg

Figures 17 through 23 show deviations of the pressures indicated by the three gages having useful scale ranges greater than 1 mm Hg absolute from the absolute pressure as determined with the calibrated Wallace & Tiernan aneroid gage for the several gases used in the test series. The absolute pressures determined with the calibration data for the Wallace & Tiernan gage are shown on the abscissae of these curves and the deviations of the Kinney McLeod gage, the Hastings thermocouple gage, (Model VT-4S), and the CVC Pirani gage are shown on the ordinates.

Although the applicable scale of the CVC Pirani gage had a marked range of only 2 mm Hg (2000 microns) deviations are plotted for absolute pressures far above 2 mm Hg because the gage continued to indicate on scale. Results obtained with the Pirani gage are omitted from Figures 21 and 22 because the indicated pressures did not exceed 0.8 mm Hg (800 microns) for absolute test pressures approaching 20 mm Hg.

Figures 17 through 23 show that the deviations for the CVC Pirani gage and the Hastings thermocouple gage were excessively large for all test pressures greater than about 1 mm Hg and for all gases used for test. Furthermore, the Kinney McLeod gage was of no practical value for measuring low absolute pressures of saturated air or water vapor, as indicated in Figures 19 and 20.

Figures 24 through 31 show deviations of the pressures indicated by some or all of the gage specimens from the absolute pressures determined with one or both of the calibrated references gages for the range of absolute pressure from approximately 20 to 900 microns Hg and for all of the test gases. The Kinney McLeod gage was used as the reference gage for absolute pressures below about 150 microns and the Wallace & Tiernan aneroid gage was used as the reference gage for absolute pressures above about 200 microns. No results are shown in Figures 27 and 28 for pressures below 200 microns Hg when saturated air and water vapor were used as the test gases because of the probability of error in the McLeod reference gage due to condensed water vapor.

In Figure 24, the deviations of the Wallace & Tiernan aneroid gage are shown for the test using nitrogen. These deviations are the calibration values for this gage, and would be the same for all tests in this pressure range, since the pressure indication of the Wallace & Tiernan aneroid gage would be unaffected by the composition or nature of the test gas.

Comparison of Figure 16 with Figures 24 through 31 indicates that on the average, in the absolute pressure range from 200 to 900 microns Hg, the lowest deviations from absolute pressure would be observed with the Wallace & Tiernan aneroid gage for refrigerant R12 and for saturated air and water vapor, whereas slightly lower average deviations were observed with Kinney McLeod gage for laboratory air and refrigerant R11. The average deviations of the ASCO thermocouple gage and the Kinney McLeod gage were lower than those of the Wallace & Tiernan aneroid gage for dry air and nitrogen. The average deviations of the ASCO thermocouple gage and the Wallace & Tiernan gage were approximately equal in this pressure range for refrigerant R22. None of the gages except the Wallace & Tiernan aneroid gage was very satisfactory throughout this pressure range when used with saturated air or water vapor.

Since the pressure indication of the Kinney McLeod gage was probably unaffected by any constituent of the test gas except water vapor, a comparison of Figure 16 with Figures 24 through 26, and Figures 29 through 31 indicates that, in the pressure range below 150 microns Hg, the lowest deviations from absolute pressure would be observed with the Kinney McLeod gage. However, the deviations of the NRC thermocouple gage were quite low for refrigerants R11, R12 and R22 and the deviations of the ASCO thermocouple gage and the CVC Pirani gage were quite low for nitrogen and dry air in this same pressure range.

In Figures 32 through 34 the deviations of the observed pressures from the absolute pressures determined by the Wallace & Tiernan reference gage are shown for the Kinney McLeod gage, the CVC Pirani gage, and the Hastings thermocouple gage, Model VT-4S, respectively. In these figures, the deviations for all gases used for the test of a single gage, are shown in one graph for comparison. These three gages all had working scale ranges greater than 1 mm Hg.

Figure 32 shows that the Kinney McLeod gage had a much different error characteristic for saturated air and for water vapor than for any other test gas. The deviations were approximately the same for nitrogen, dry air, laboratory air, and the three refrigerant gases, and ranged from about 10 to 15 percent of the absolute test pressure.

The results observed with the CVC Pirani gage for water vapor, R11 and R12 are shown in Figure 33 for test pressures up to about 14 mm Hg because the instrument continued to indicate on scale even though the maximum scale range was only 2 mm Hg. Other gases used for the tests produced similar results to those shown in Figure 33. The data in the figure show that the deviations ranged from about 90 to 95 percent of the absolute pressure.

The results in Figure 34 for the Hastings thermocouple gage show that the gage indicated too high a pressure for nitrogen, dry air, and laboratory air whereas it indicated considerably below the absolute pressure for the three refrigerant gases and for water vapor and saturated air for the upper portion of the range of test pressures used. This gage read too high for all gases in the absolute pressure range from 0 to about 3 mm Hg.

Figures 35 through 40 show the results of tests of a particular gage when tested with some or all of the test gases at absolute pressures up to 1000 microns Hg (1 mm Hg). In these figures the calibrated Wallace & Tiernan aneroid gage was used as the reference gage for pressures above 200 microns Hg and the calibrated Kinney McLeod gage was used as a reference gage for pressures below 150 microns Hg. No data are shown for the 0 to 150 micron Hg pressure range for tests with water vapor or saturated air because of the limitations of the McLeod gage with respect to condensable vapors. The data shown in Figures 35 through 40 are the same data shown in Figures 24 through 31, but with all data on a single gage shown on the same graph in Figures 35 through 40 whereas all data with a single gas were grouped together in the other figures.

Figures 35, 37, and 40 show that the Kinney McLeod gage, the NRC thermocouple gage, and the CVC Pirani gage were not very sensitive to the type of gas in the pressure range below 1000 microns except that the Kinney McLeod gage was significantly in error when water vapor or saturated air was used as the test gas. Figures 36, 38 and 39 show that three of the thermocouple gages were significantly more sensitive to the type of gas used for the test. In Figure 36 it is shown that the deviations of the ASCO thermocouple gage were quite low throughout the pressure range from 0 to 1000 microns Hg for dry air and nitrogen, and somewhat greater for refrigerants R11 and R22. In Figure 37 the NRC thermocouple gage revealed low deviations for the three refrigerant gases for pressures up to about 200 microns Hg. By comparing Figures 35 and 40, it is seen that the indications of the CVC Pirani gage were somewhat more consistent for the different gases than the indications of the Kinney McLeod gage in the pressure range from 200 to 1000 microns Hg. The deviations of the Pirani gage were a little higher at the upper end of this pressure range except for water vapor and saturated air.

Figure 41 shows the repeatability of observed deviations of each of two gages during two different test runs with nitrogen. The values plotted are the deviations from the corrected absolute pressures determined by the aneroid reference gage.

Figure 42 shows the observed deviation, in mm Hg, of the Kinney McLeod gage from the corrected Wallace & Tiernan absolute pressure reference values during a test with dry air as the gas, and may be compared with Figure 41 (with nitrogen) and with Table 3 (calibration by NBS Pressure Measurement Section).

In all the graphs shown in Figures 15 through 42, the deviation above the reference line is the amount the test gage indicated higher than the reference absolute pressure and should be subtracted from the observed value to obtain the absolute pressure, likewise, the deviation value below the reference line should be added to the observed pressure to obtain the absolute pressure.

6. DISCUSSION AND CONCLUSIONS

Refrigerating systems that need evacuation under service conditions are likely to contain refrigerant gas and room air mixed in any proportions. Since room air always contains some moisture, there is the possibility that some free moisture would exist in the refrigerant circuit especially if air entered the system while it was cold. When free moisture exists in a system under evacuation, water vapor will probably be the last gas to leave the system because water has a lower vapor pressure than any other fluid in the system except the oil. In order to remove water from a system by evaporation and evacuation, the pressure in the system must be decreased to the range from 22.2 to 5.2 mm Hg for ambient temperatures in the range from 75°F to 35°F in order to evaporate the water. Thus, it is evident that the gages used to indicate evacuation pressures in the field must provide reasonable accuracy for saturated air and water vapor in addition to the refrigerant gas employed in the system for pressures considerably below 20 mm Hg. Furthermore, gages used for field service must be reasonably rugged in construction and simple to use.

The comparisons made in this study of several gages indicate that the Wallace & Tiernan aneroid gage is probably best suited to the needs of the Defense Department for field and shop evacuation service of refrigerating systems because its indication is not affected by the type or composition of the gas, its accuracy is quite good down to absolute pressures of 1 mm Hg or lower, it does not require a battery or other source of electric power, it does not require any manipulations or adjustment by the operator, and it is quite rugged in construction. It might be desirable to request a wire-reinforced glass face for the gage to decrease the hazards of breakage.

The McLeod gages would have usefulness where water vapor or saturated gases were not involved and where the tilting or lever movements required could be safely and effectively accomplished. The Pirani gage, and the NRC and ASCO thermocouple gages could be used for reasonably accurate pressure indications for some gases and for selected ranges of pressure below 1000 microns Hg absolute.

Although the scales for Pirani and thermocouple-type gages, such as those included in this study, are typically graduated for use with dry air as the reference gas, these instruments could probably be furnished with scales graduated for some other gas, e.g. refrigerant R12 or R22, if desired.

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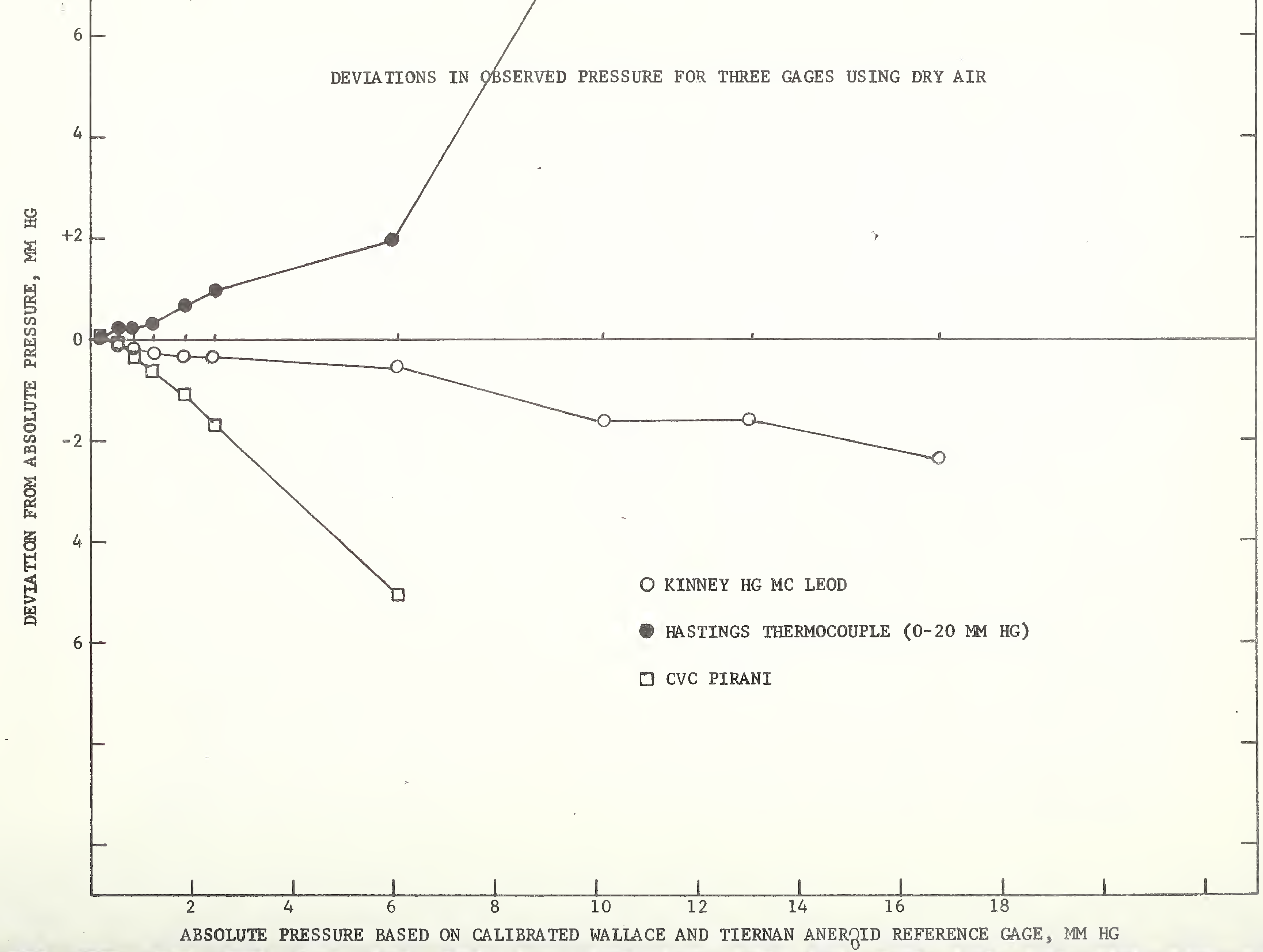
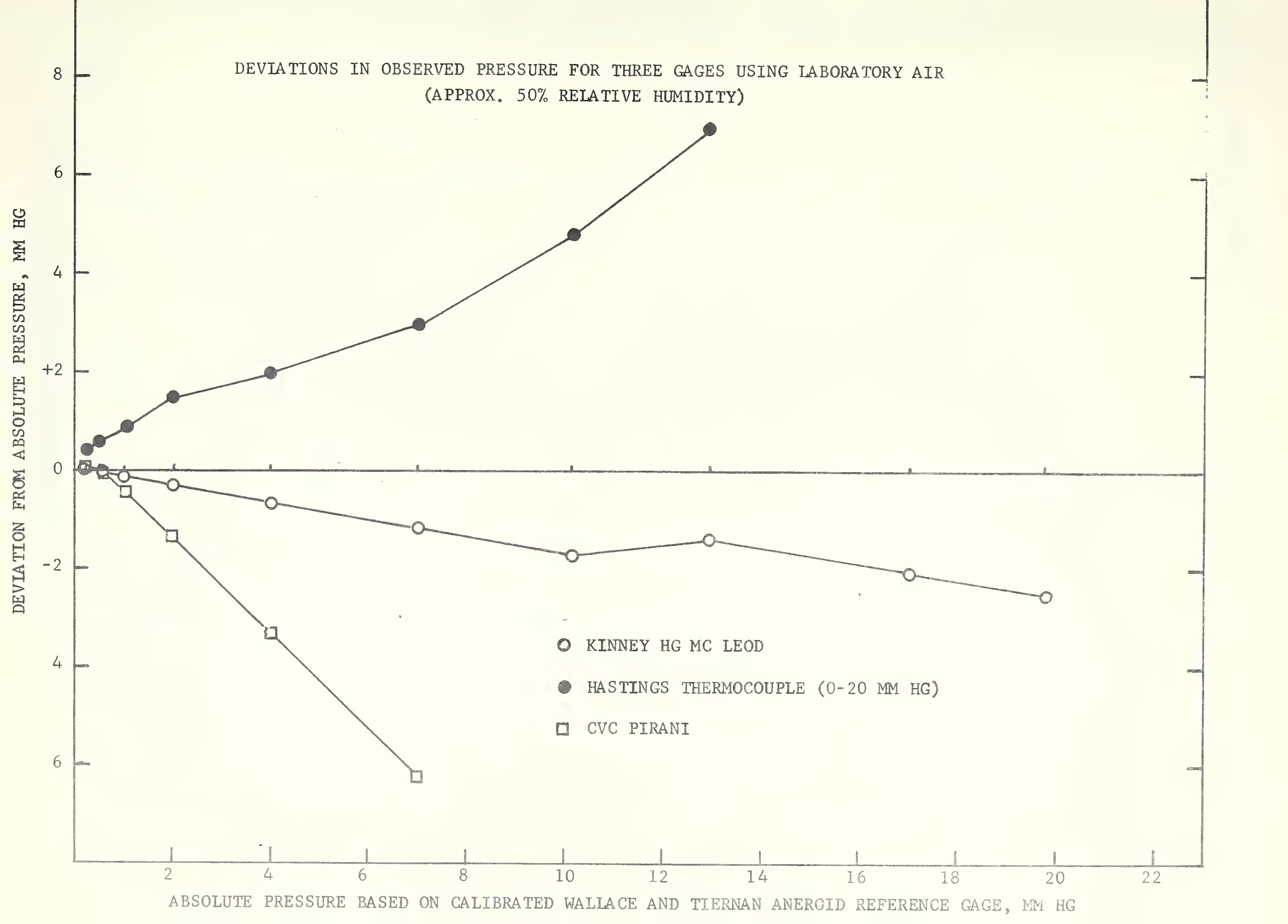
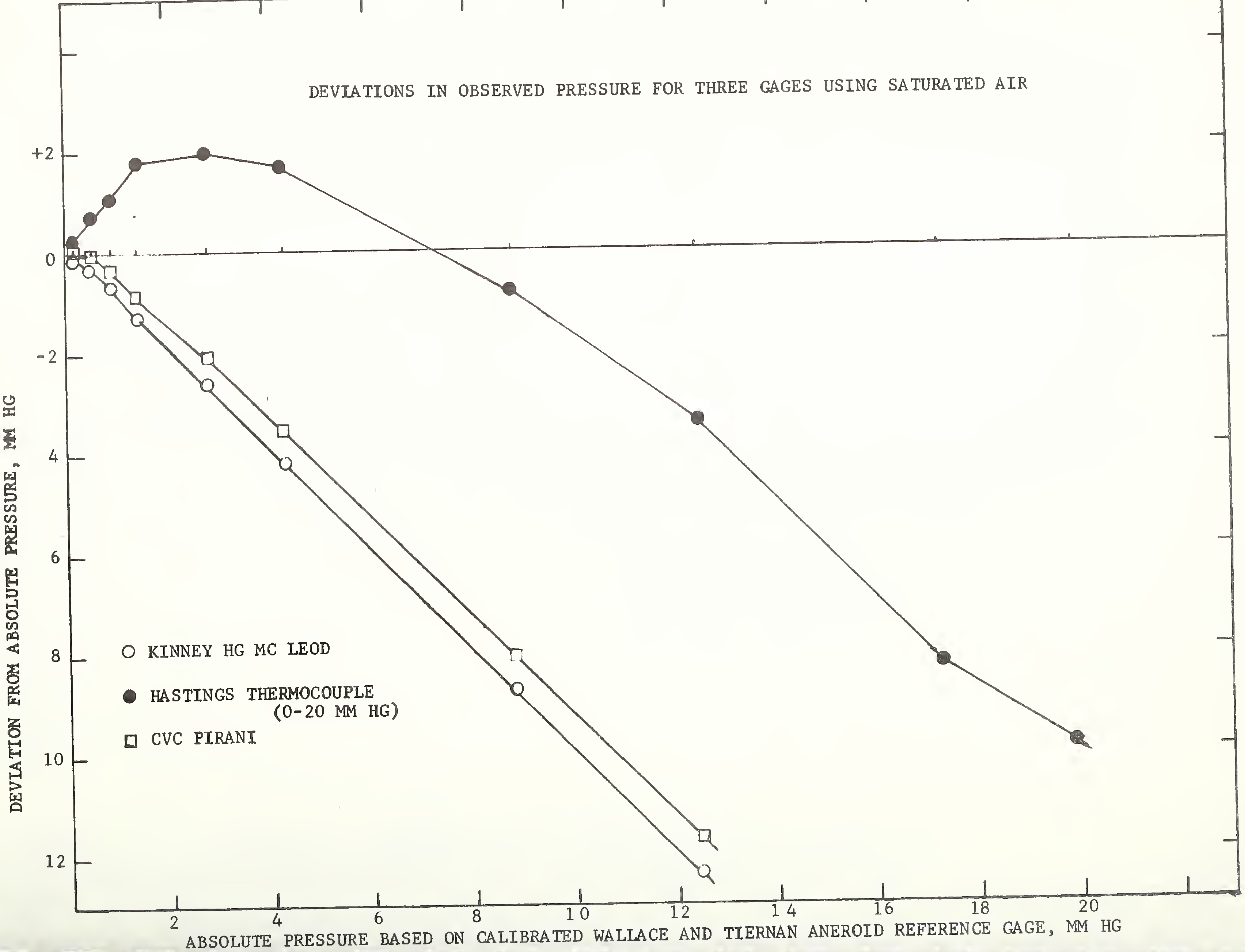

DEVIATIONS IN OBSERVED PRESSURE FOR THREE GAGES USING DRY AIR
DEVIATION FROM ABSOLUTE PRESSURE, MM HG
6
4
+2
0
-2
4
6
2
4
6
8
10
12
14
16
18
ABSOLUTE PRESSURE BASED ON CALIBRATED WALLACE AND TIERNAN ANEROID REFERENCE GAGE, MM HG
KINNEY HG MC LEOD
HASTINGS THERMOCOUPLE (0-20 MM HG)
CVC PIRANI

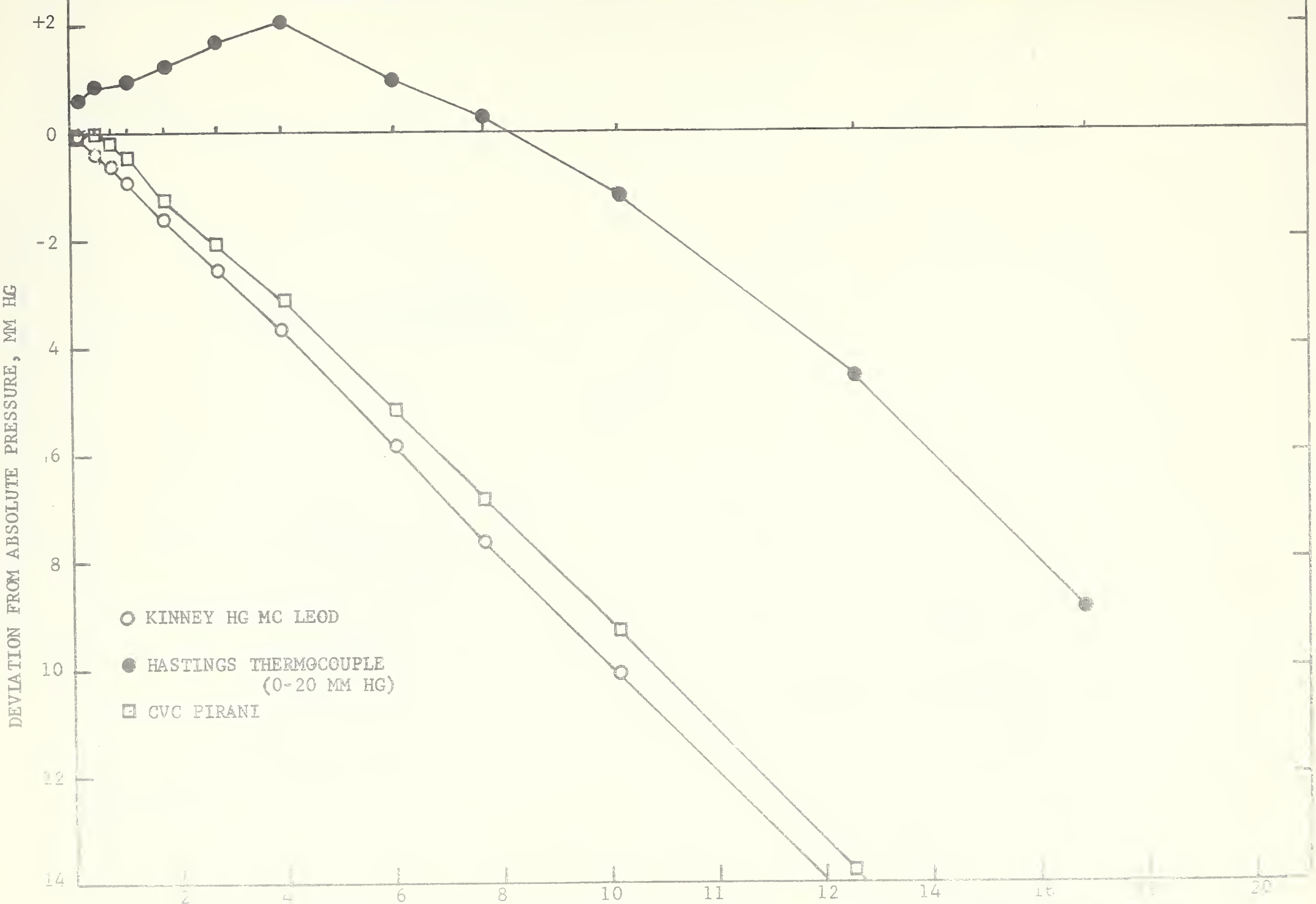


DEVIATIONS IN OBSERVED PRESSURE FOR THREE GAGES USING LABORATORY AIR
(APPROX. 50% RELATIVE HUMIDITY)
KINNEY HG MC LEOD
HASTINGS THERMOCOUPLE (0-20 MM HG)
CVC PIRANI
DEVIATION FROM ABSOLUTE PRESSURE, MM HG
8
6
4
+2
0
-2
4
6
2
4
6
8
10
12
14
16
18
20
22
ABSOLUTE PRESSURE BASED ON CALIBRATED WALLACE AND TIERNAN ANEROID REFERENCE GAGE, MM HG



DEVIATIONS IN OBSERVED PRESSURE FOR THREE GAGES USING SATURATED AIR
+2
0
-2
4
6
8
10
12
DEVIATION FROM ABSOLUTE PRESSURE, MM HG
2
4
6
8
10
12
14
16
18
20
ABSOLUTE PRESSURE BASED ON CALIBRATED WALLACE AND TIERNAN ANEROID REFERENCE GAGE, MM HG
○ KINNEY HG MC LEOD
● HASTINGS THERMOCOUPLE (0-20 MM HG)
□ CVC PIRANI

DEVIATIONS IN OBSERVED PRESSURE FOR THREE GAGES USING WATER VAPOR



ABSOLUTE PRESSURE BASED ON CALIBRATED WALLACE AND TIERNAN ANEROID REFERENCE

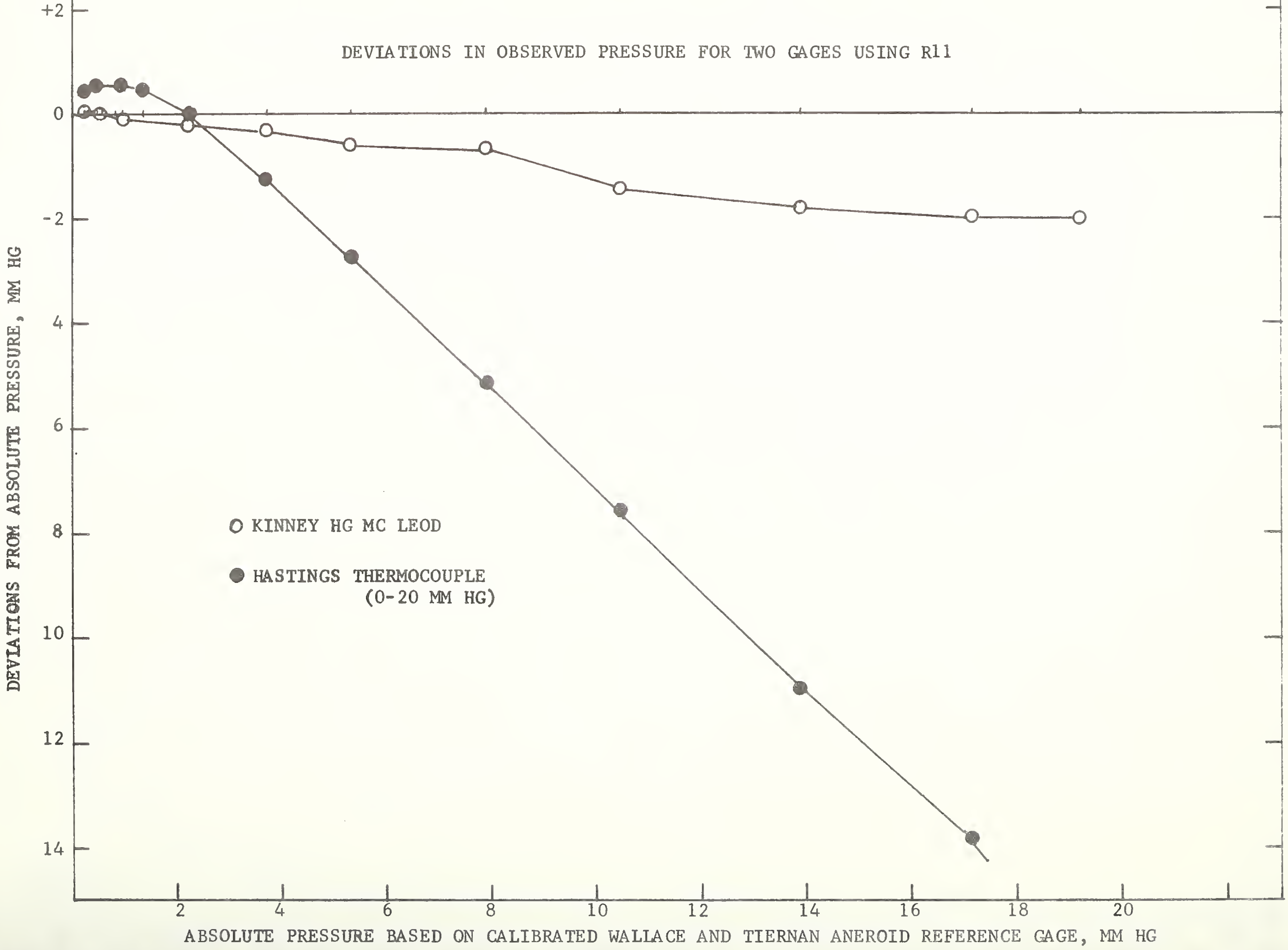

DEVIATIONS IN OBSERVED PRESSURE FOR TWO GAGES USING R11
O KINNEY HG MC LEOD
● HASTINGS THERMOCOUPLE
(0-20 MM HG)
DEVIATIONS FROM ABSOLUTE PRESSURE, MM HG
+2
0
-2
4
6
8
10
12
14
2
4
6
8
10
12
14
16
18
20
ABSOLUTE PRESSURE BASED ON CALIBRATED WALLACE AND TIERNAN ANEROID REFERENCE GAGE, MM HG

FIGURE 21

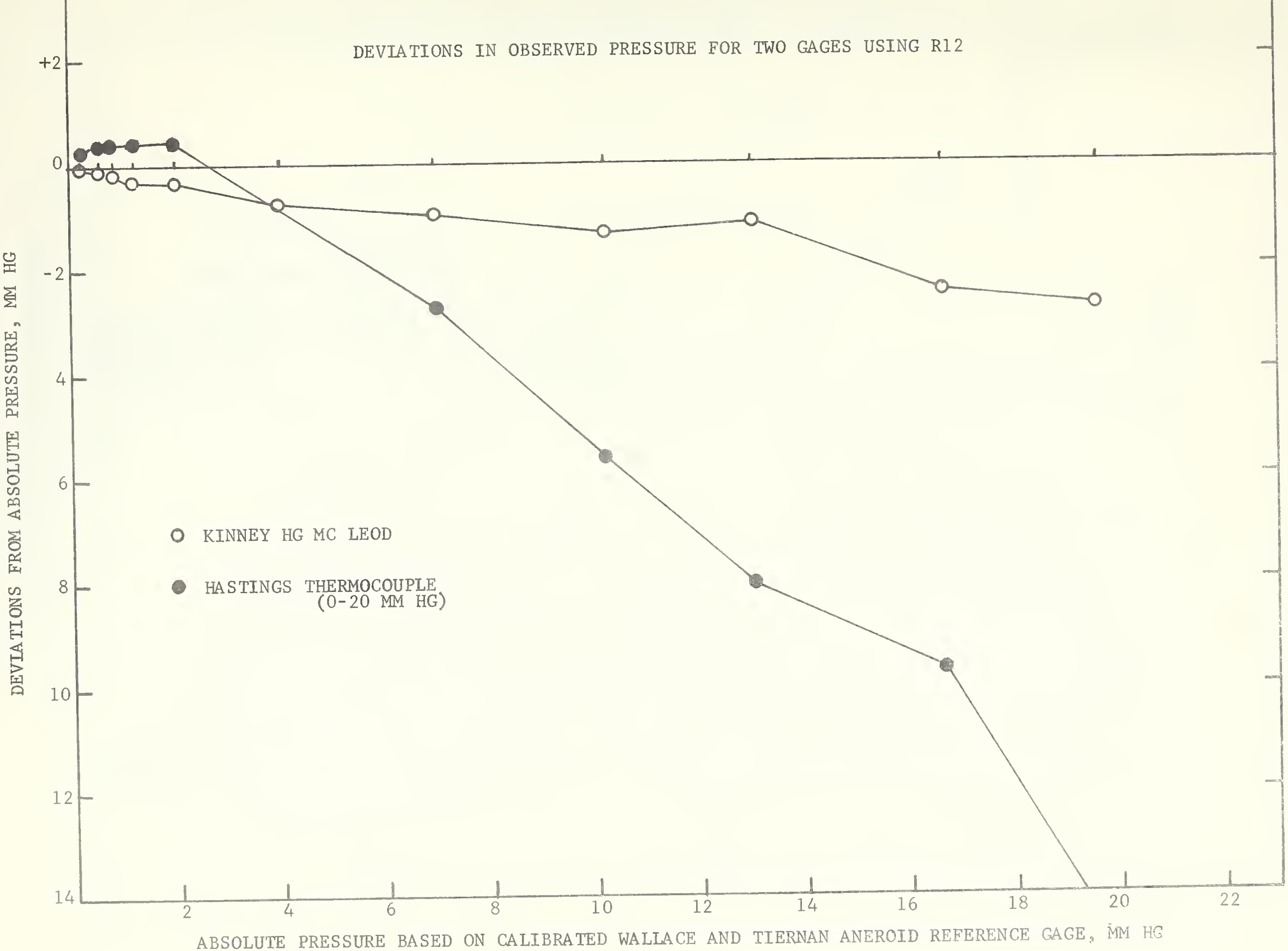
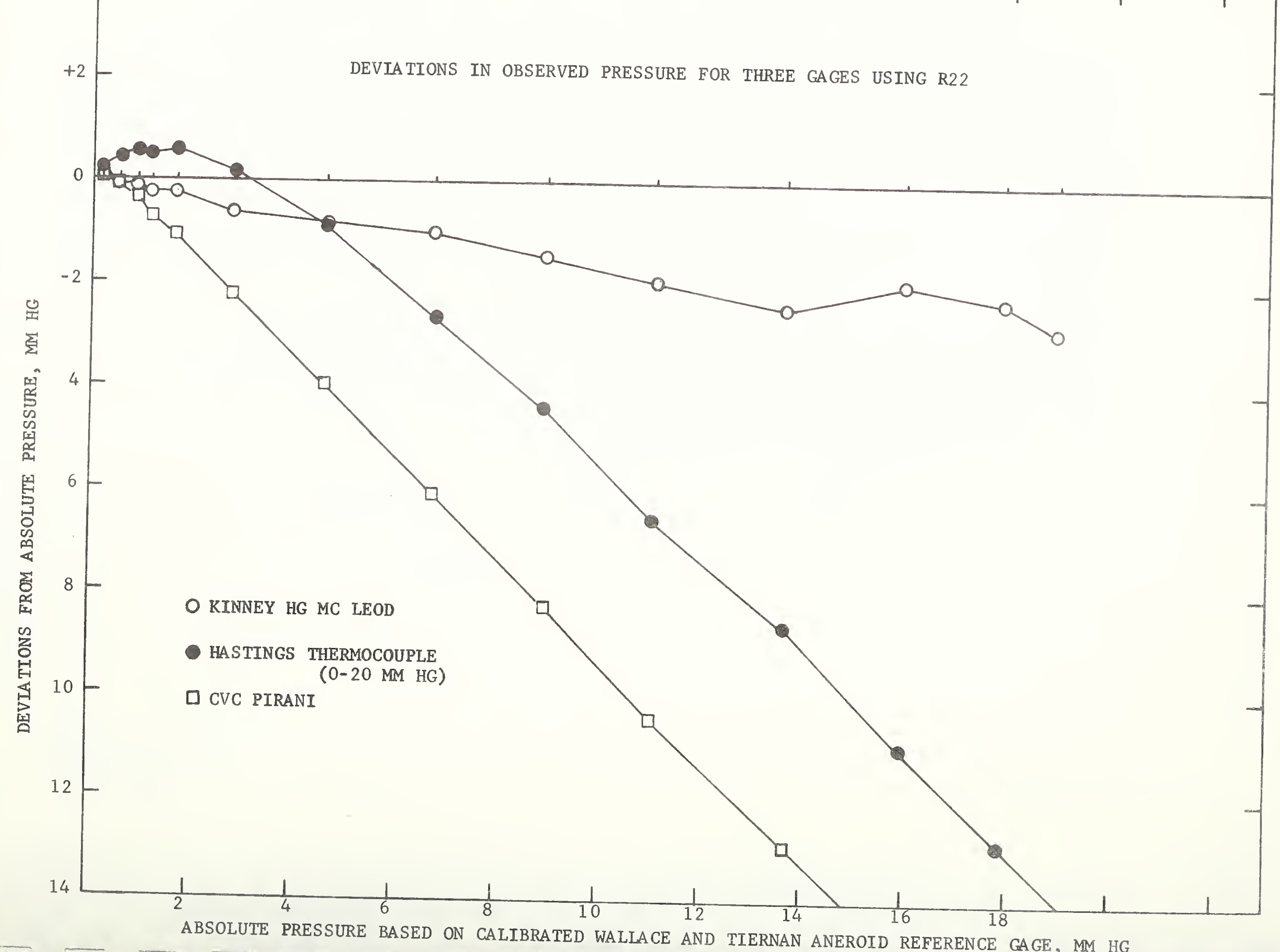
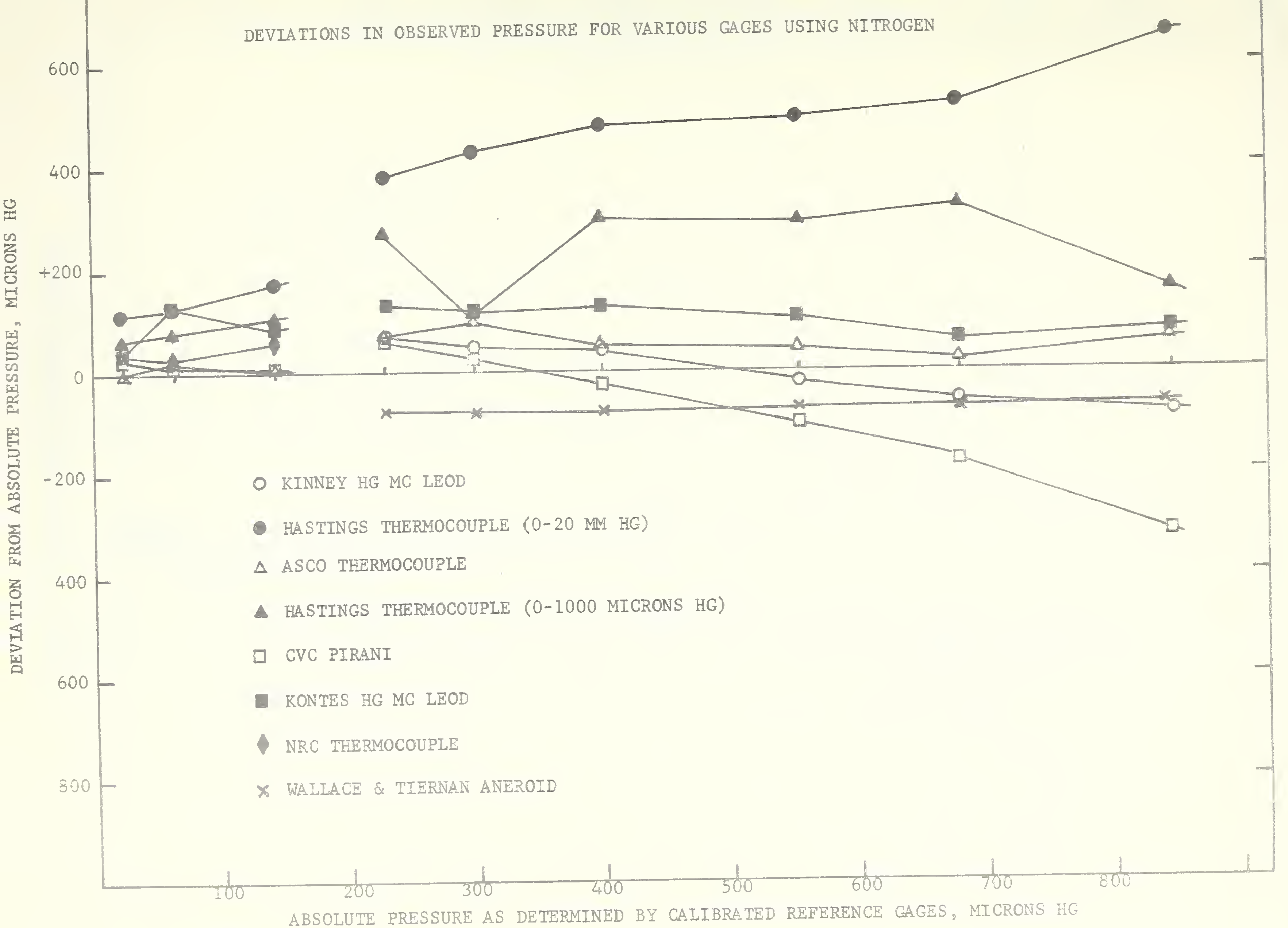

DEVIATIONS IN OBSERVED PRESSURE FOR TWO GAGES USING R12
+2
0
-2
4
6
8
10
12
14
DEVIATIONS FROM ABSOLUTE PRESSURE, MM HG
KINNEY HG MC LEOD
HASTINGS THERMOCOUPLE (0-20 MM HG)
2
4
6
8
10
12
14
16
18
20
22
ABSOLUTE PRESSURE BASED ON CALIBRATED WALLACE AND TIERNAN ANEROID REFERENCE GAGE, MM HG

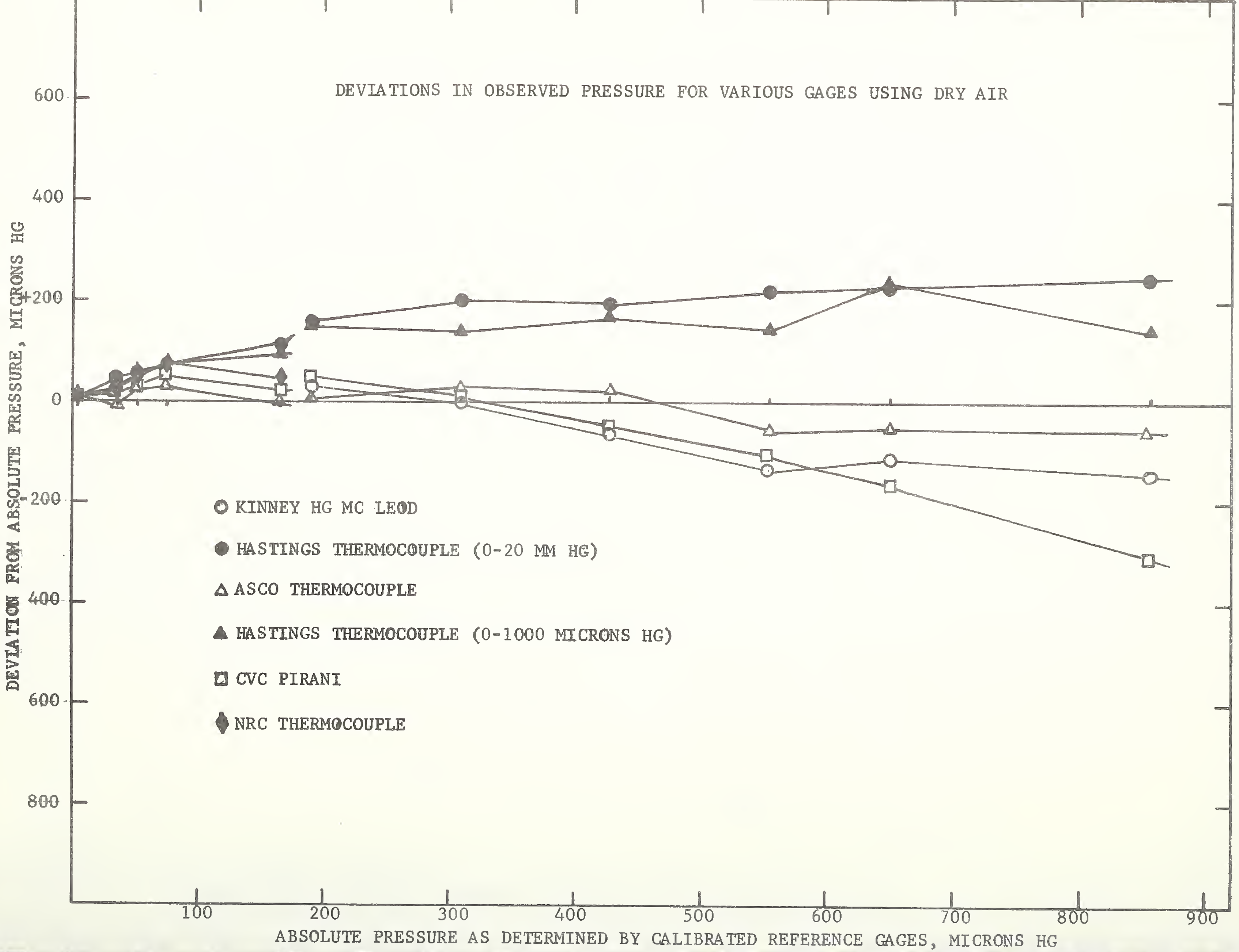
FIGURE 22


DEVIATIONS IN OBSERVED PRESSURE FOR THREE GAGES USING R22
KINNEY HG MC LEOD
HASTINGS THERMOCOUPLE (0-20 MM HG)
CVC PIRANI
DEVIATIONS FROM ABSOLUTE PRESSURE, MM HG
ABSOLUTE PRESSURE BASED ON CALIBRATED WALLACE AND TIERNAN ANEROID REFERENCE GAGE, MM HG
+2
0
-2
4
6
8
10
12
14
2
4
6
8
10
12
14
16
18



DEVIATIONS IN OBSERVED PRESSURE FOR VARIOUS GAGES USING NITROGEN
600
400
+200
0
-200
400
600
800
DEVIATION FROM ABSOLUTE PRESSURE, MICRONS HG
KINNEY HG MC LEOD
HASTINGS THERMOCOUPLE (0-20 MM HG)
ASCO THERMOCOUPLE
HASTINGS THERMOCOUPLE (0-1000 MICRONS HG)
CVC PIRANI
KONTES HG MC LEOD
NRC THERMOCOUPLE
WALLACE & TIERNAN ANEROID
100
200
300
400
500
600
700
800
ABSOLUTE PRESSURE AS DETERMINED BY CALIBRATED REFERENCE GAGES, MICRONS HG

FIGURE 24



DEVIATIONS IN OBSERVED PRESSURE FOR VARIOUS GAGES USING DRY AIR
KINNEY HG MC LEOD
HASTINGS THERMOCOUPLE (0-20 MM HG)
ASCO THERMOCOUPLE
HASTINGS THERMOCOUPLE (0-1000 MICRONS HG)
CVC PIRANI
NRC THERMOCOUPLE
DEVIATION FROM ABSOLUTE PRESSURE, MICRONS HG
600
400
+200
0
-200
400
600
800
100
200
300
400
500
600
700
800
900
ABSOLUTE PRESSURE AS DETERMINED BY CALIBRATED REFERENCE GAGES, MICRONS HG

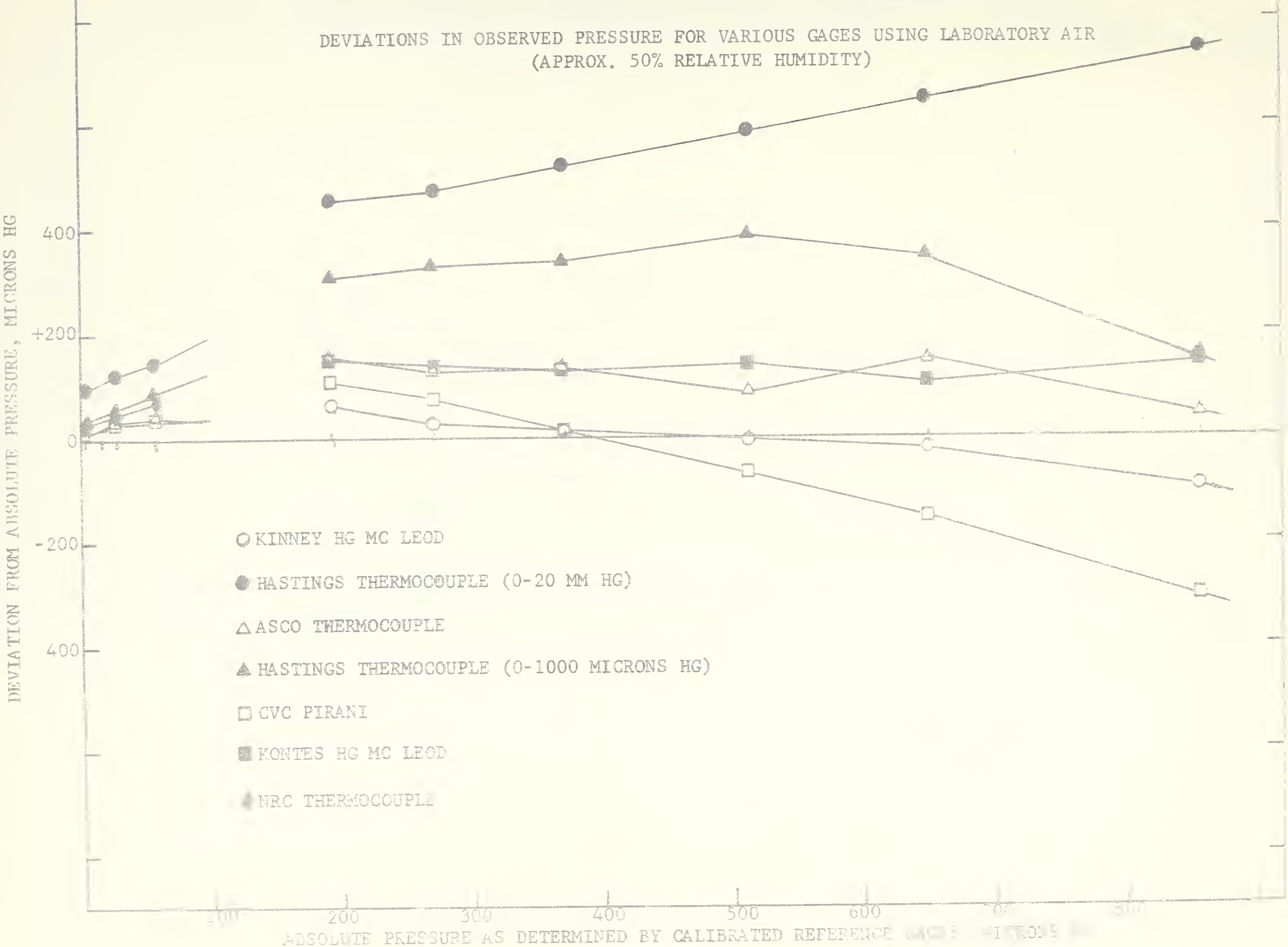
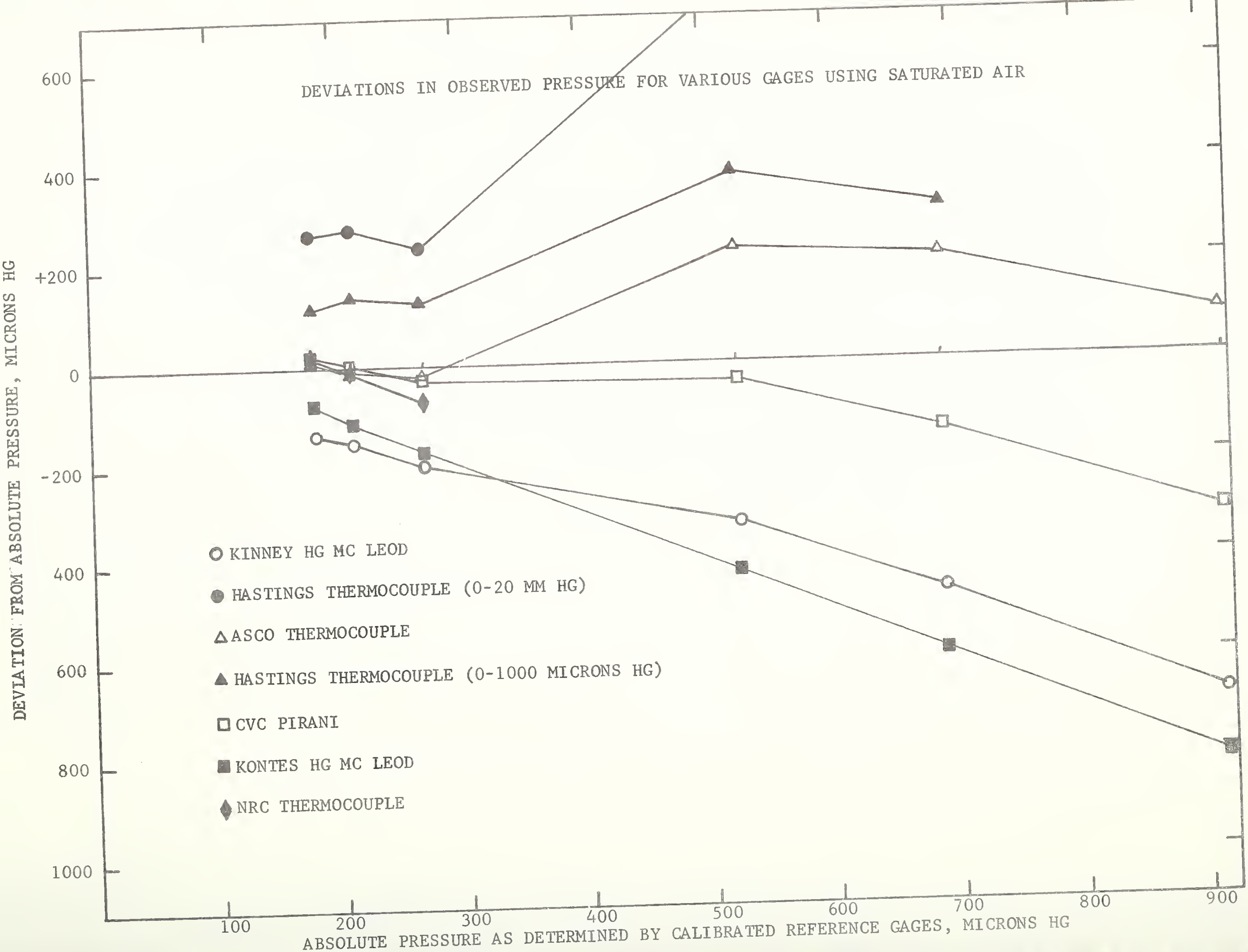

DEVIATIONS IN OBSERVED PRESSURE FOR VARIOUS GAGES USING LABORATORY AIR
(APPROX. 50% RELATIVE HUMIDITY)
DEVIATION FROM ABSOLUTE PRESSURE, MICRONS HG
400
+200
0
-200
400
200
300
400
500
600
ABSOLUTE PRESSURE AS DETERMINED BY CALIBRATED REFERENCE
KINNEY HG MC LEOD
HASTINGS THERMOCOUPLE (0-20 MM HG)
ASCO THERMOCOUPLE
HASTINGS THERMOCOUPLE (0-1000 MICRONS HG)
CVC PIRANI
KONTES HG MC LEOD
NRC THERMOCOUPLE

FIGURE 26


DEVIATIONS IN OBSERVED PRESSURE FOR VARIOUS GAGES USING SATURATED AIR
600
400
+200
0
-200
400
600
800
1000
DEVIATION FROM ABSOLUTE PRESSURE, MICRONS HG
100
200
300
400
500
600
700
800
900
ABSOLUTE PRESSURE AS DETERMINED BY CALIBRATED REFERENCE GAGES, MICRONS HG
KINNEY HG MC LEOD
HASTINGS THERMOCOUPLE (0-20 MM HG)
ASCO THERMOCOUPLE
HASTINGS THERMOCOUPLE (0-1000 MICRONS HG)
CVC PIRANI
KONTES HG MC LEOD
NRC THERMOCOUPLE

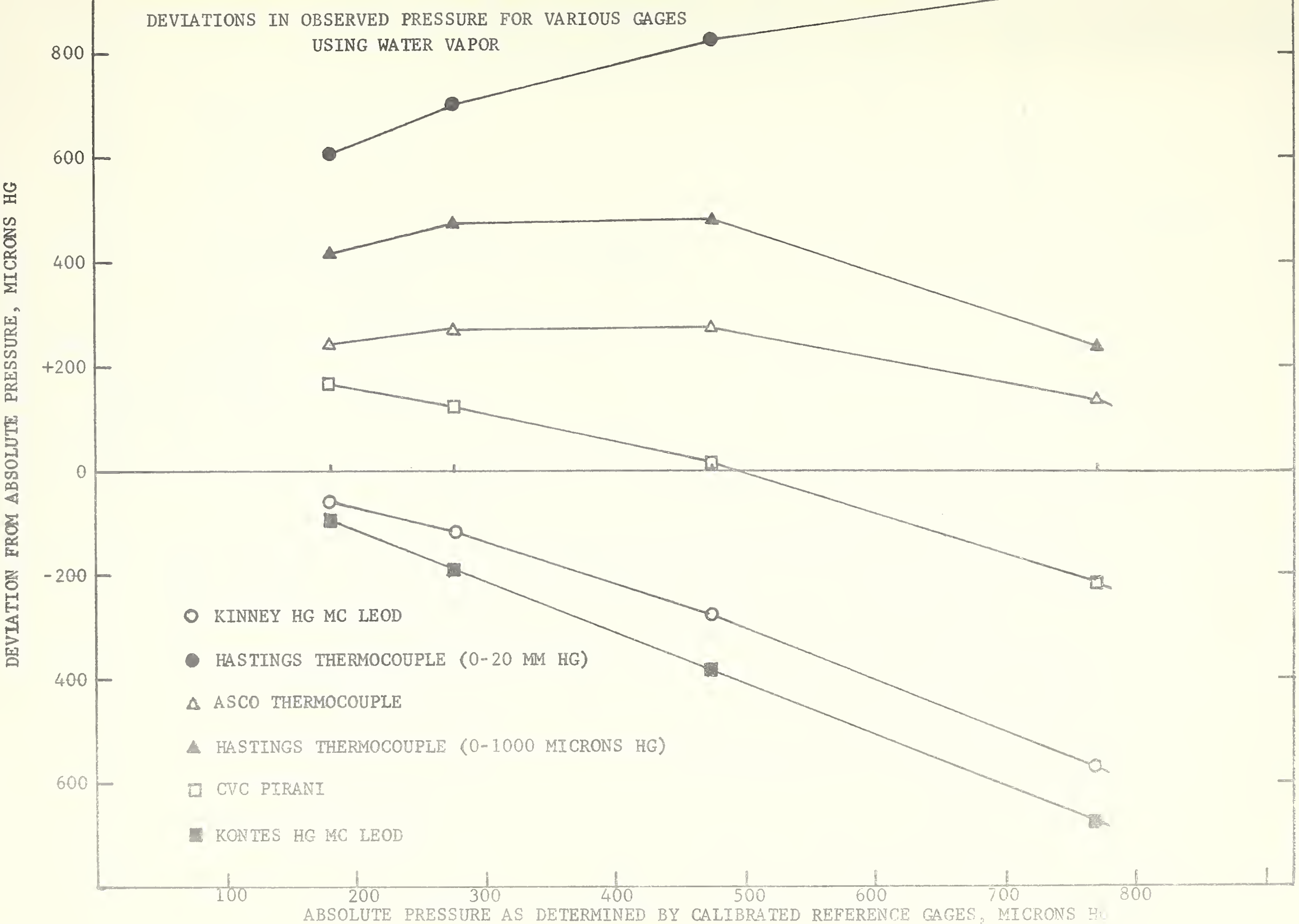
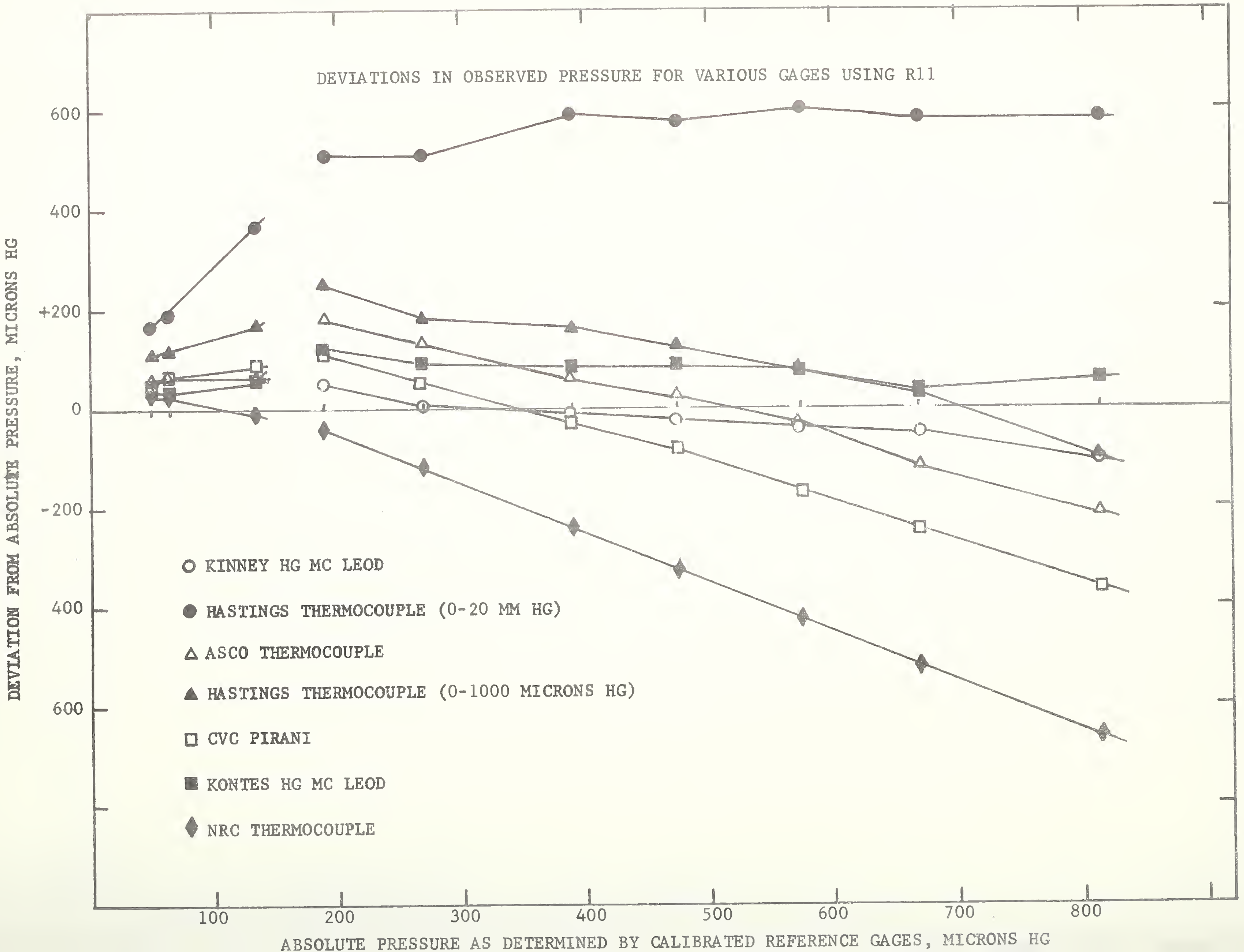
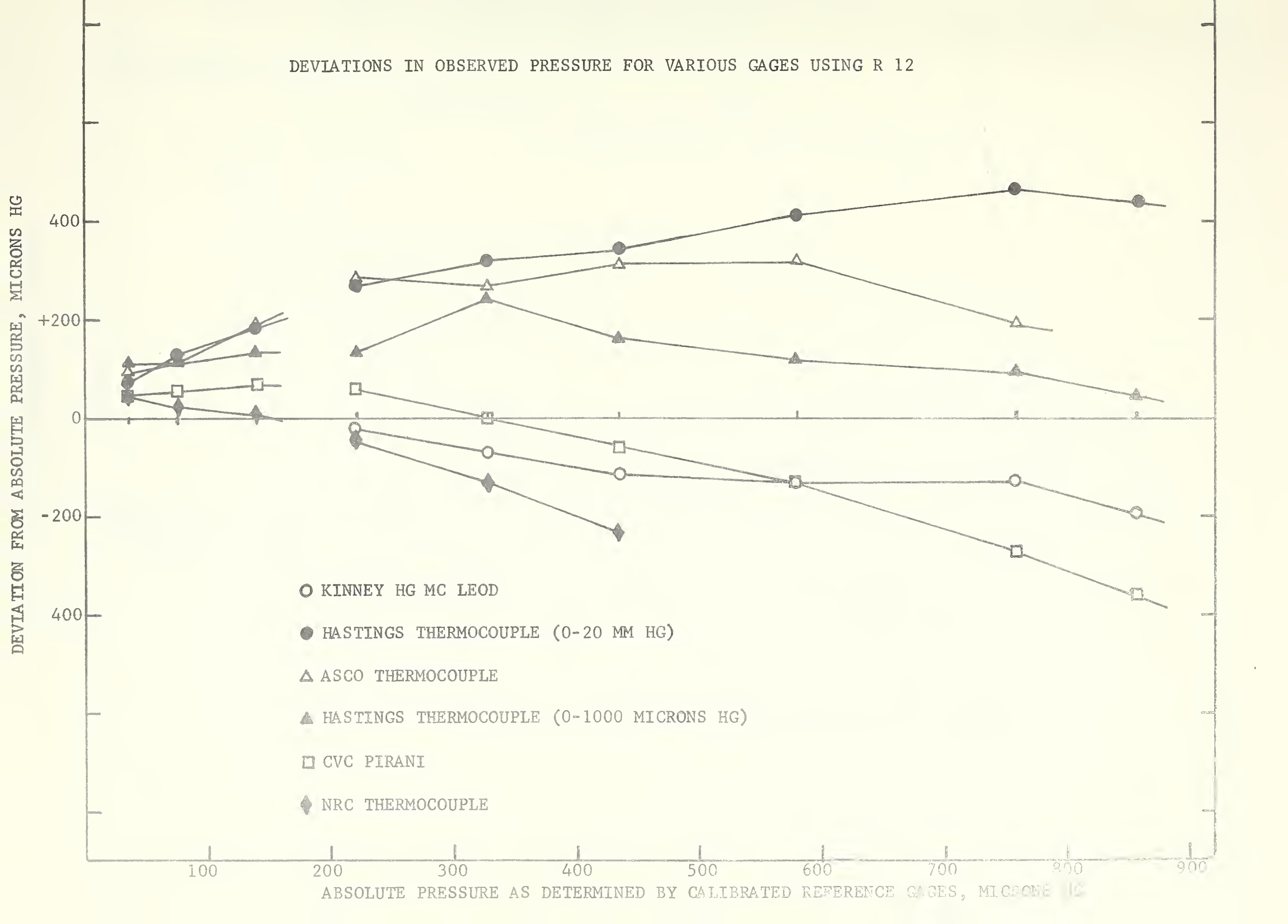
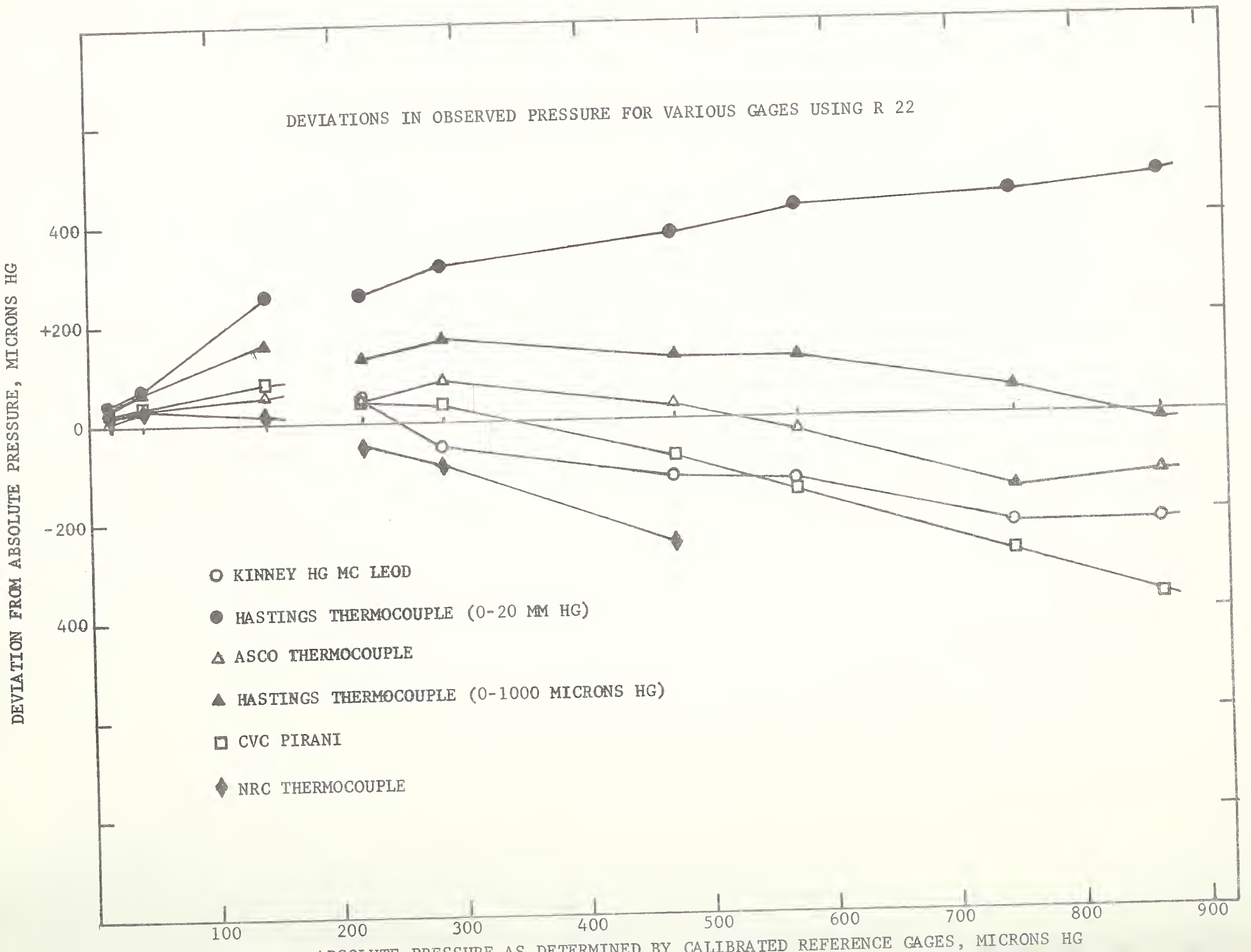

DEVIATIONS IN OBSERVED PRESSURE FOR VARIOUS GAGES
USING WATER VAPOR
800
600
400
+200
0
-200
400
600
DEVIATION FROM ABSOLUTE PRESSURE, MICRONS HG
KINNEY HG MC LEOD
HASTINGS THERMOCOUPLE (0-20 MM HG)
ASCO THERMOCOUPLE
HASTINGS THERMOCOUPLE (0-1000 MICRONS HG)
CVC PIRANI
KONTES HG MC LEOD
100
200
300
400
500
600
700
800
ABSOLUTE PRESSURE AS DETERMINED BY CALIBRATED REFERENCE GAGES, MICRONS HG

FIGURE 28


DEVIATIONS IN OBSERVED PRESSURE FOR VARIOUS GAGES USING R11
600
400
+200
0
-200
400
600
DEVIATION FROM ABSOLUTE PRESSURE, MICRONS HG
KINNEY HG MC LEOD
HASTINGS THERMOCOUPLE (0-20 MM HG)
ASCO THERMOCOUPLE
HASTINGS THERMOCOUPLE (0-1000 MICRONS HG)
CVC PIRANI
KONTES HG MC LEOD
NRC THERMOCOUPLE
100
200
300
400
500
600
700
800
ABSOLUTE PRESSURE AS DETERMINED BY CALIBRATED REFERENCE GAGES, MICRONS HG


DEVIATIONS IN OBSERVED PRESSURE FOR VARIOUS GAGES USING R 12
DEVIATION FROM ABSOLUTE PRESSURE, MICRONS HG
400
+200
0
-200
400
KINNEY HG MC LEOD
HASTINGS THERMOCOUPLE (0-20 MM HG)
ASCO THERMOCOUPLE
HASTINGS THERMOCOUPLE (0-1000 MICRONS HG)
CVC PIRANI
NRC THERMOCOUPLE
100
200
300
400
500
600
700
800
900
ABSOLUTE PRESSURE AS DETERMINED BY CALIBRATED REFERENCE GAGES, MICRONS HG


DEVIATIONS IN OBSERVED PRESSURE FOR VARIOUS GAGES USING R 22
DEVIATION FROM ABSOLUTE PRESSURE, MICRONS HG
400
+200
0
-200
400
KINNEY HG MC LEOD
HASTINGS THERMOCOUPLE (0-20 MM HG)
ASCO THERMOCOUPLE
HASTINGS THERMOCOUPLE (0-1000 MICRONS HG)
CVC PIRANI
NRC THERMOCOUPLE
100
200
300
400
500
600
700
800
900
ABSOLUTE PRESSURE AS DETERMINED BY CALIBRATED REFERENCE GAGES, MICRONS HG

DEVIATIONS IN OBSERVED PRESSURE FOR KINNEY MC LEOD GAGE USING VARIOUS GASES

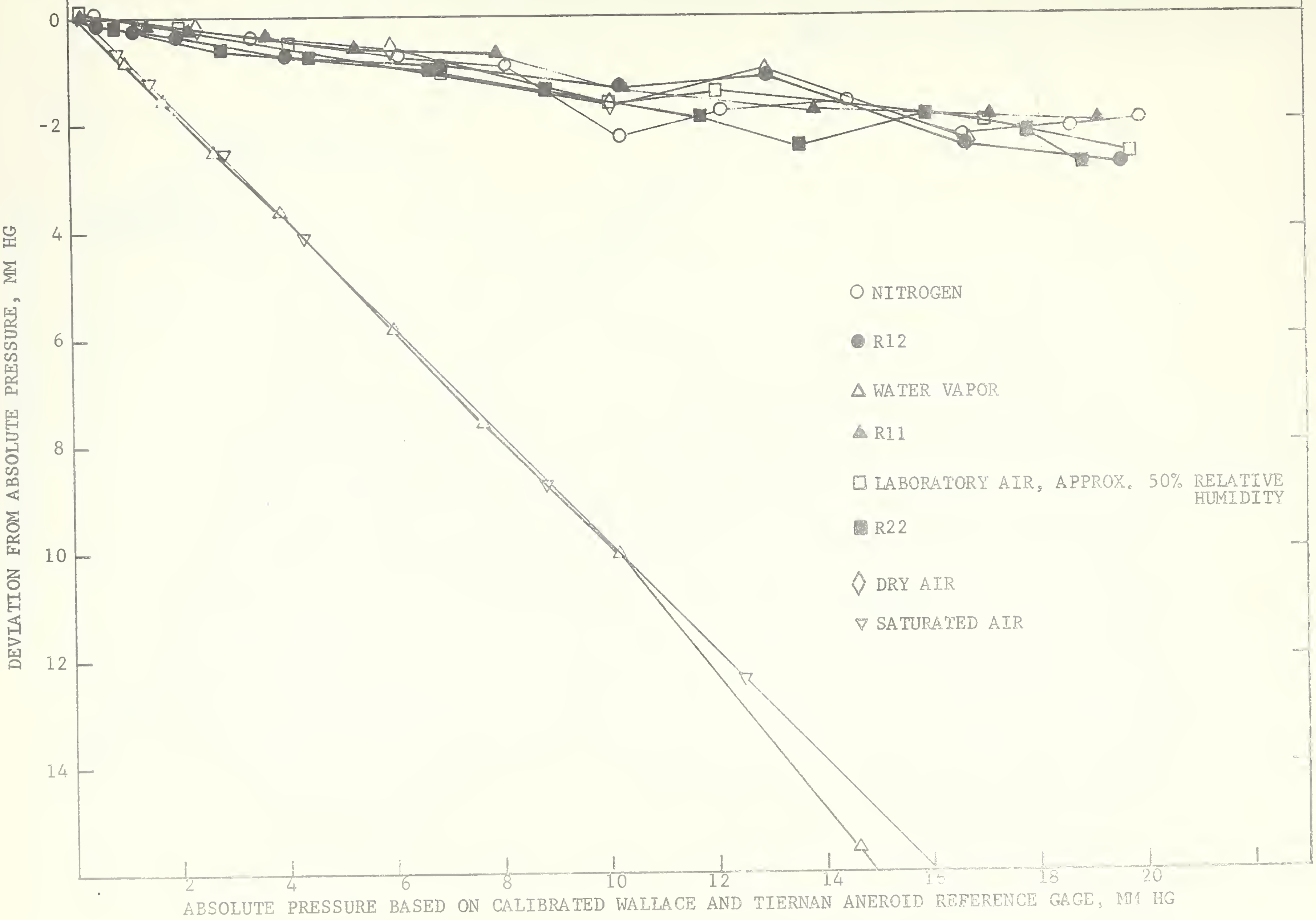
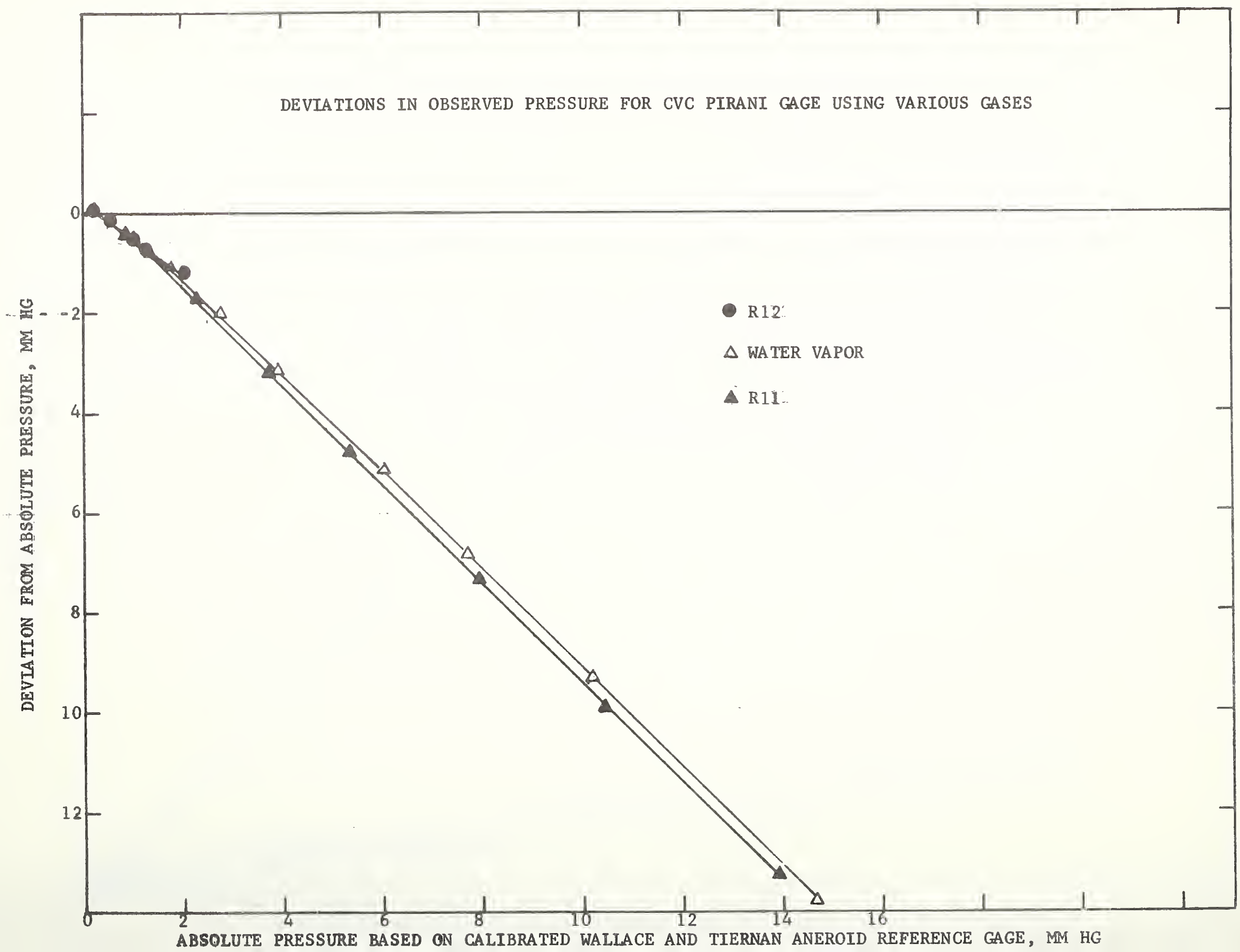


FIGURE 32


DEVIATIONS IN OBSERVED PRESSURE FOR CVC PIRANI GAGE USING VARIOUS GASES
R12
WATER VAPOR
R11
DEVIATION FROM ABSOLUTE PRESSURE, MM HG
0
2
4
6
8
10
12
14
16
ABSOLUTE PRESSURE BASED ON CALIBRATED WALLACE AND TIERNAN ANEROID REFERENCE GAGE, MM HG

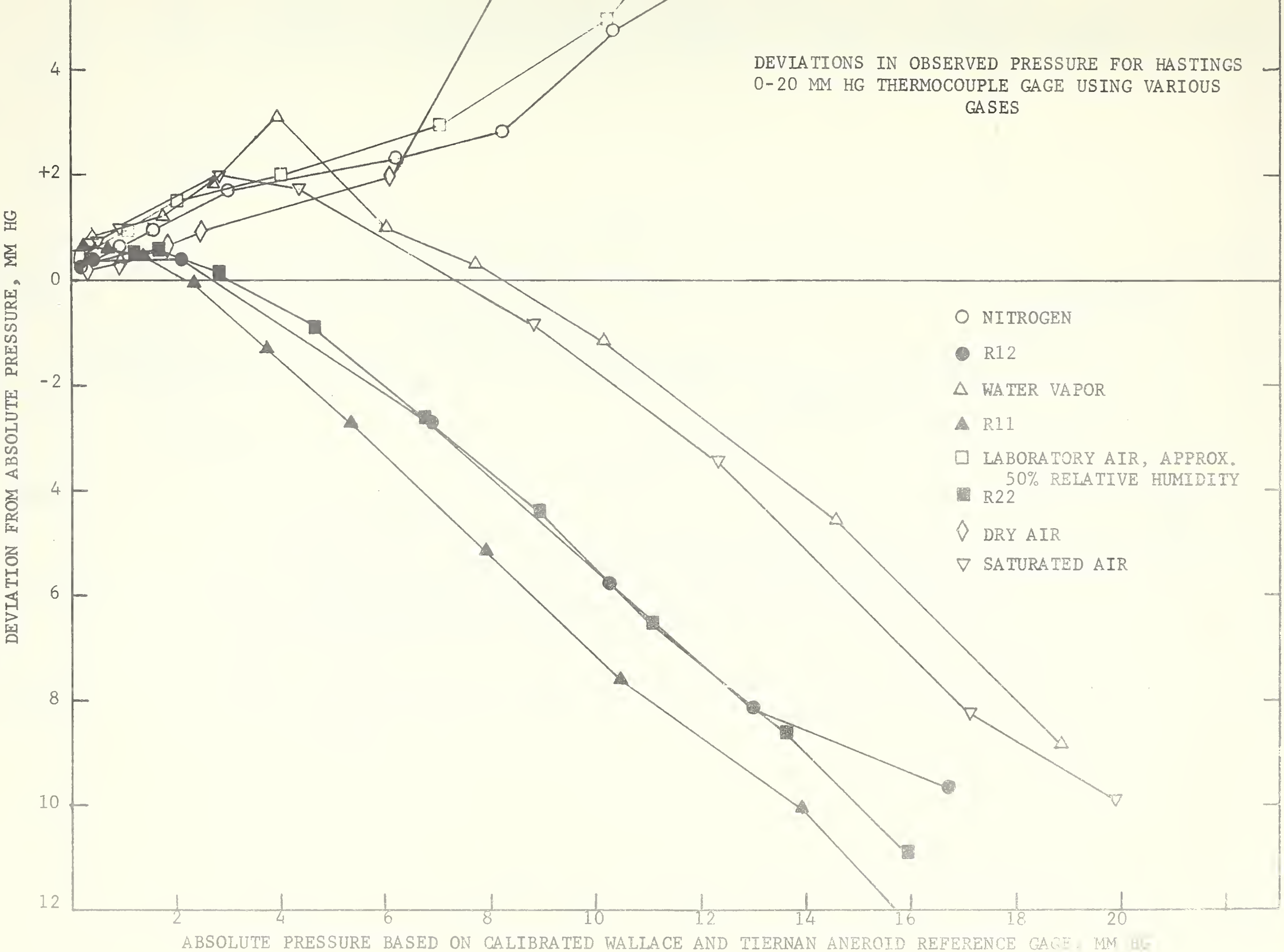
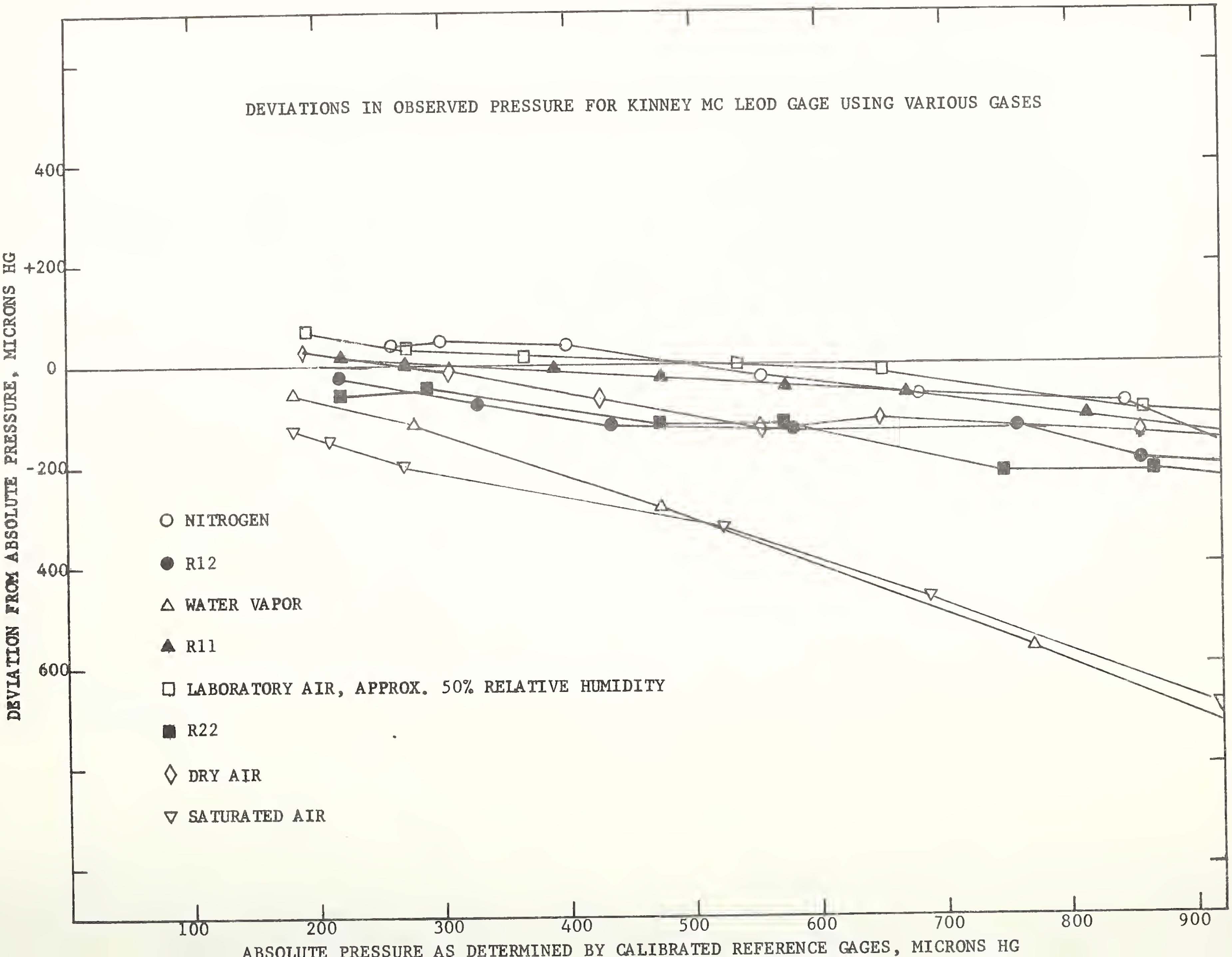

DEVIATIONS IN OBSERVED PRESSURE FOR HASTINGS
0-20 MM HG THERMOCOUPLE GAGE USING VARIOUS
GASES
NITROGEN
R12
WATER VAPOR
R11
LABORATORY AIR, APPROX.
50% RELATIVE HUMIDITY
R22
DRY AIR
SATURATED AIR
DEVIATION FROM ABSOLUTE PRESSURE, MM HG
4
+2
0
-2
4
6
8
10
12
2
4
6
8
10
12
14
16
18
20
ABSOLUTE PRESSURE BASED ON CALIBRATED WALLACE AND TIERNAN ANEROID REFERENCE GAGE, MM HG

FIGURE 34


DEVIATIONS IN OBSERVED PRESSURE FOR KINNEY MC LEOD GAGE USING VARIOUS GASES
400
+200
0
-200
400
600
100
200
300
400
500
600
700
800
900
DEVIATION FROM ABSOLUTE PRESSURE, MICRONS HG
ABSOLUTE PRESSURE AS DETERMINED BY CALIBRATED REFERENCE GAGES, MICRONS HG
NITROGEN
R12
WATER VAPOR
R11
LABORATORY AIR, APPROX. 50% RELATIVE HUMIDITY
R22
DRY AIR
SATURATED AIR

DEVIATIONS IN OBSERVED PRESSURE FOR ASCO THERMOCOUPLE GAGE USING VARIOUS GASES

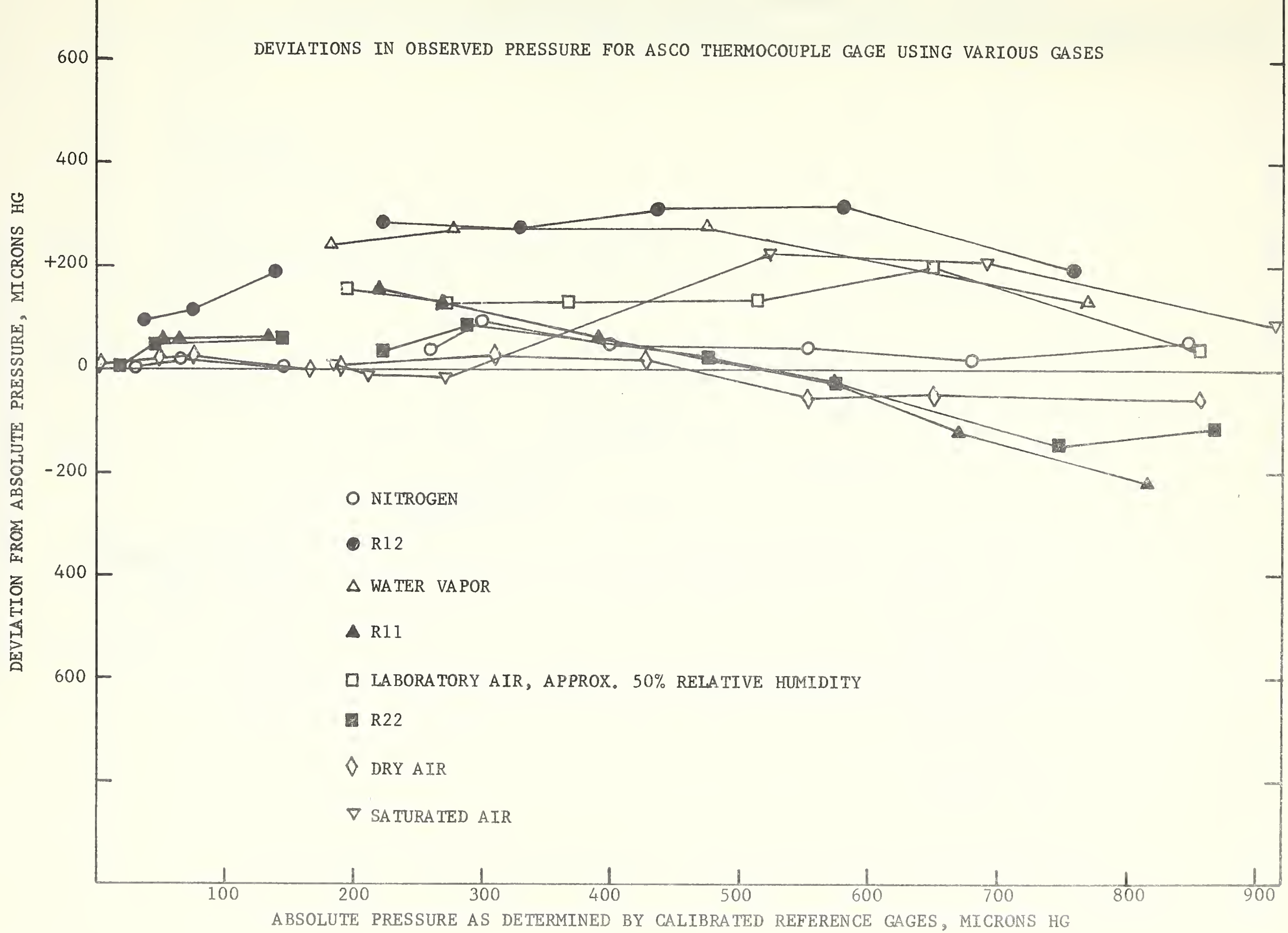
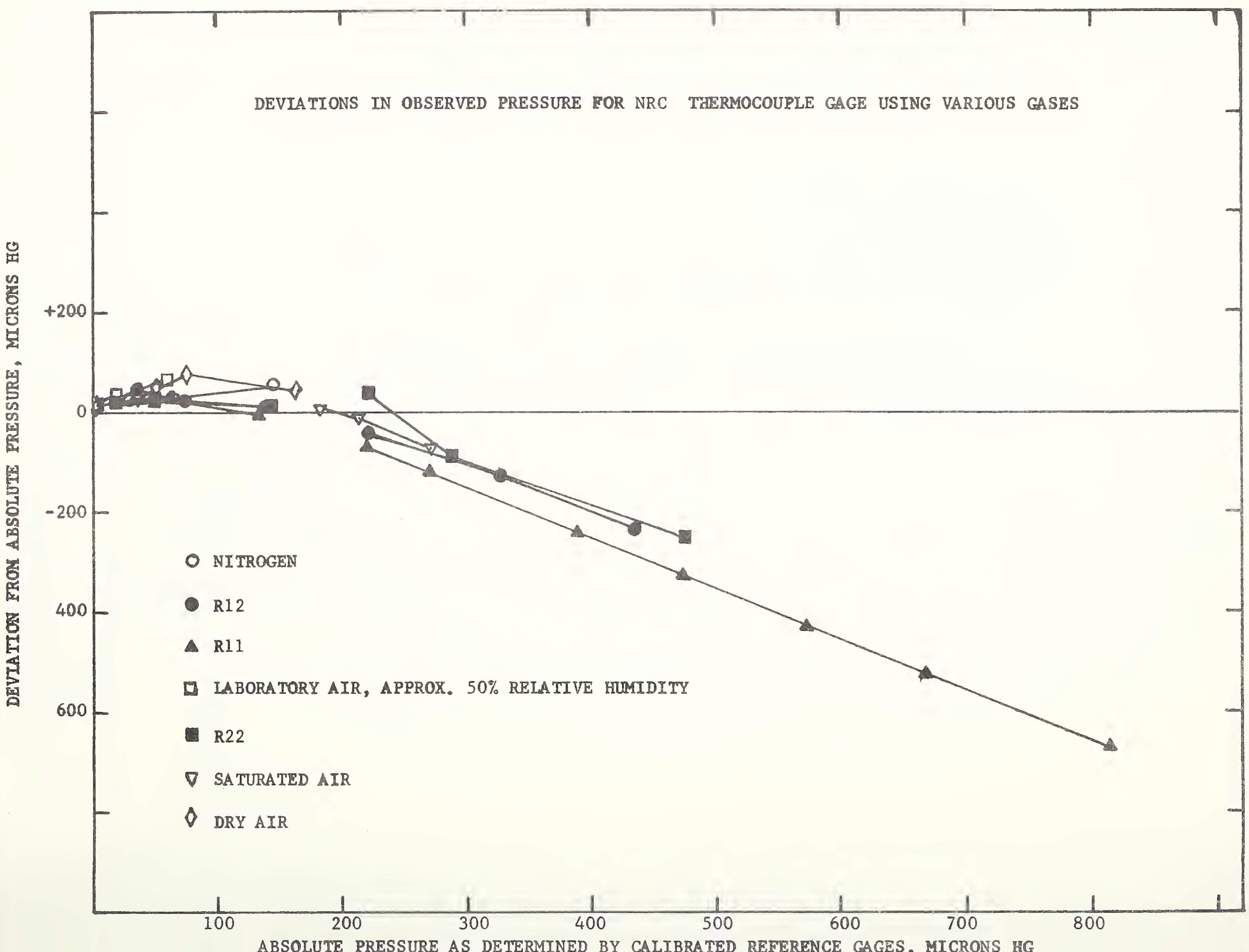
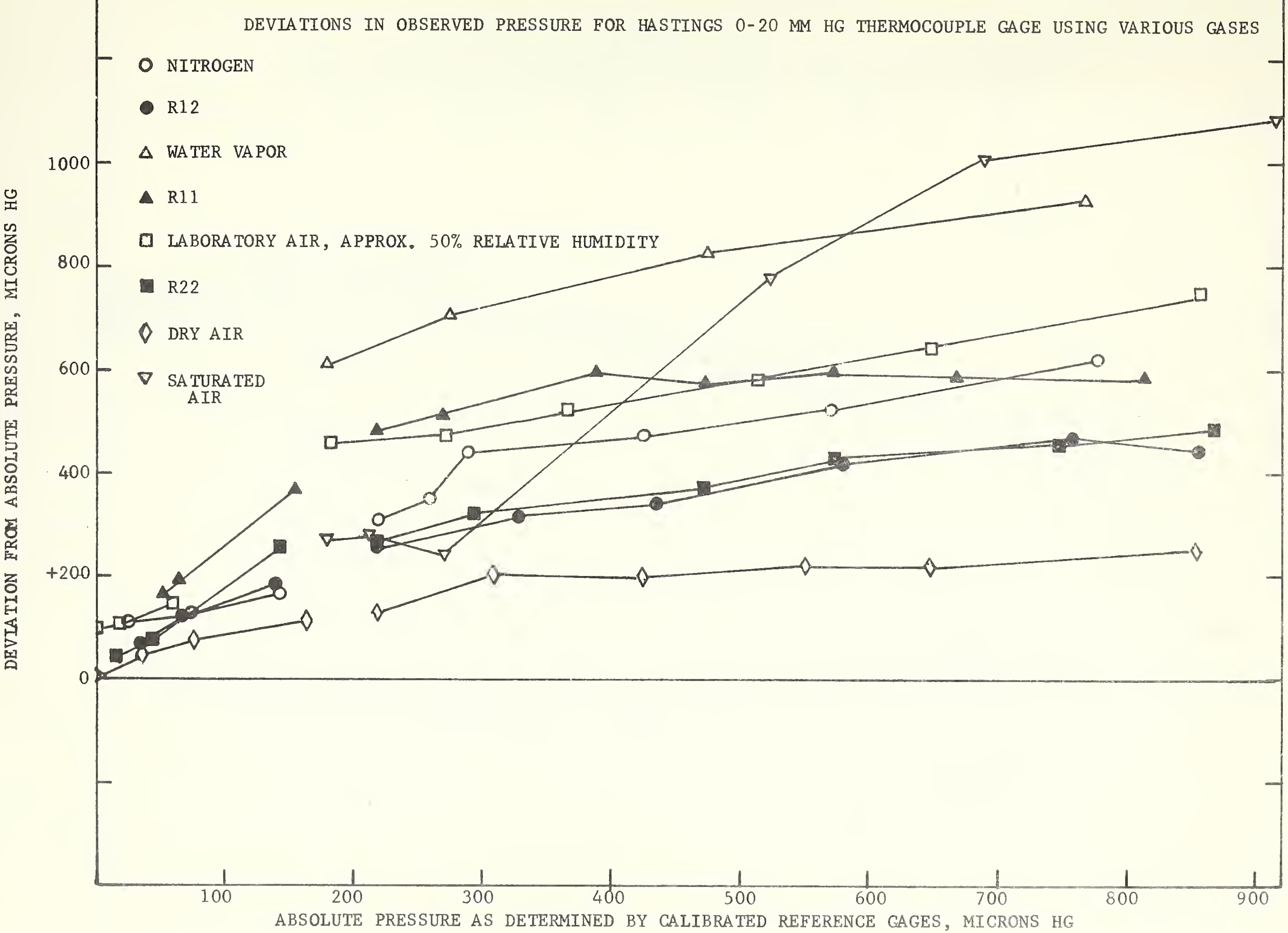


FIGURE 36


DEVIATIONS IN OBSERVED PRESSURE FOR NRC THERMOCOUPLE GAGE USING VARIOUS GASES
NITROGEN
R12
R11
LABORATORY AIR, APPROX. 50% RELATIVE HUMIDITY
R22
SATURATED AIR
DRY AIR
+200
0
-200
400
600
100
200
300
400
500
600
700
800
DEVIATION FROM ABSOLUTE PRESSURE, MICRONS HG
ABSOLUTE PRESSURE AS DETERMINED BY CALIBRATED REFERENCE GAGES, MICRONS HG



DEVIATIONS IN OBSERVED PRESSURE FOR HASTINGS 0-20 MM HG THERMOCOUPLE GAGE USING VARIOUS GASES
NITROGEN
R12
WATER VAPOR
R11
LABORATORY AIR, APPROX. 50% RELATIVE HUMIDITY
R22
DRY AIR
SATURATED AIR
DEVIATION FROM ABSOLUTE PRESSURE, MICRONS HG
1000
800
600
400
+200
0
100
200
300
400
500
600
700
800
900
ABSOLUTE PRESSURE AS DETERMINED BY CALIBRATED REFERENCE GAGES, MICRONS HG

FIGURE 38

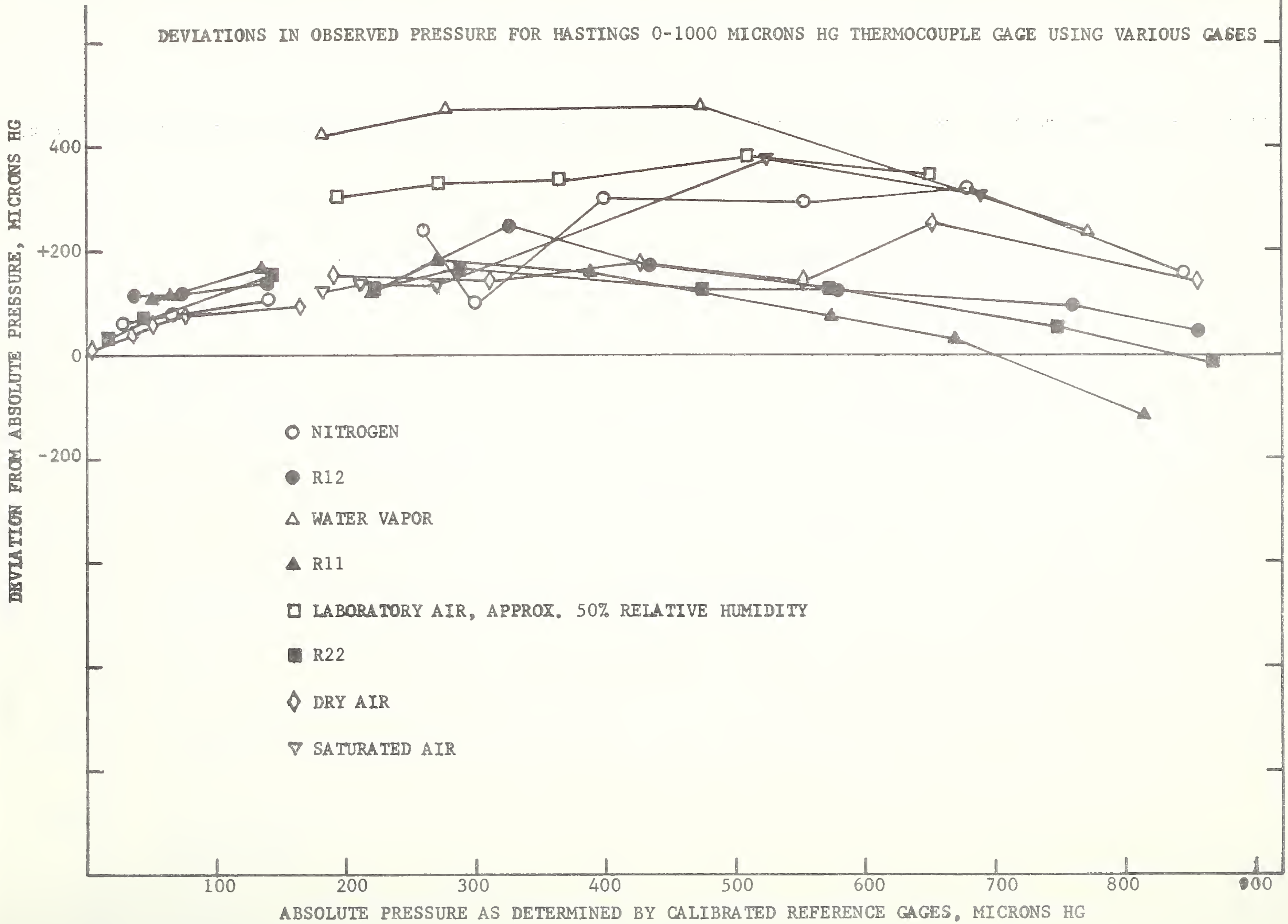

DEVIATIONS IN OBSERVED PRESSURE FOR HASTINGS 0-1000 MICRONS HG THERMOCOUPLE GAGE USING VARIOUS GASES
DEVIATION FROM ABSOLUTE PRESSURE, MICRONS HG
400
+200
0
-200
NITROGEN
R12
WATER VAPOR
R11
LABORATORY AIR, APPROX. 50% RELATIVE HUMIDITY
R22
DRY AIR
SATURATED AIR
100
200
300
400
500
600
700
800
900
ABSOLUTE PRESSURE AS DETERMINED BY CALIBRATED REFERENCE GAGES, MICRONS HG

FIGURE 39

DEVIATIONS IN OBSERVED PRESSURE FOR CVC PIRANI GAGE USING VARIOUS GASES

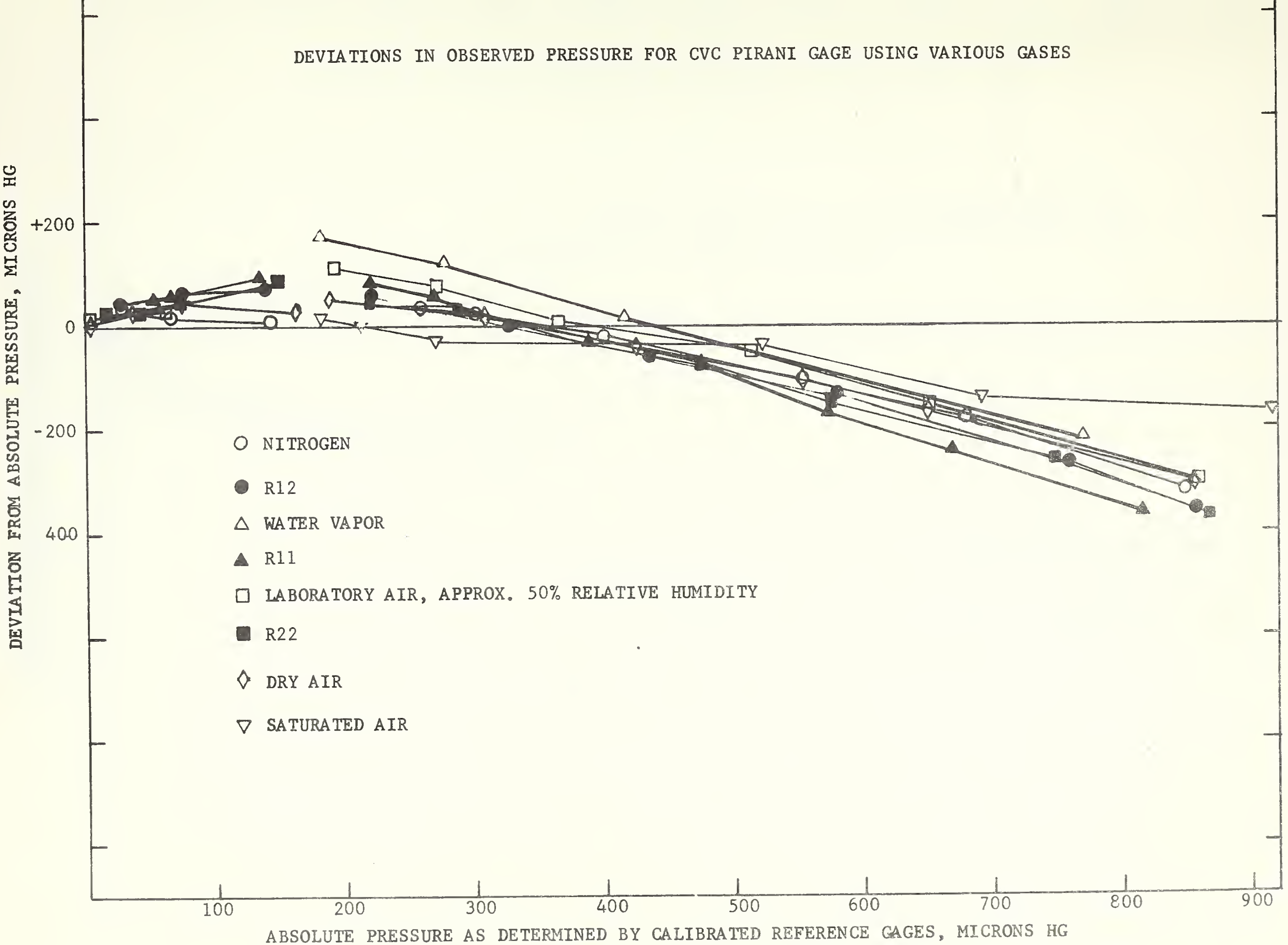
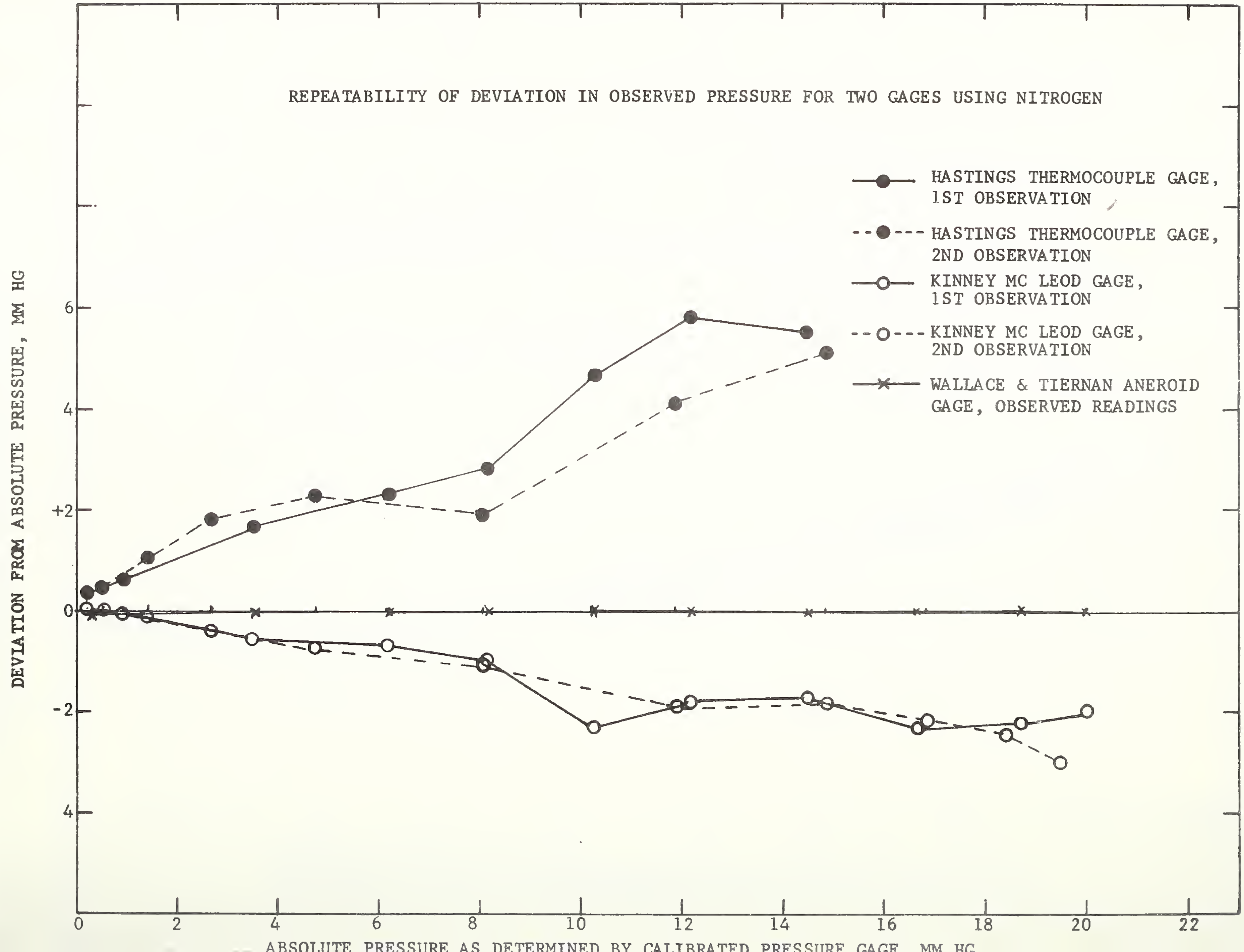
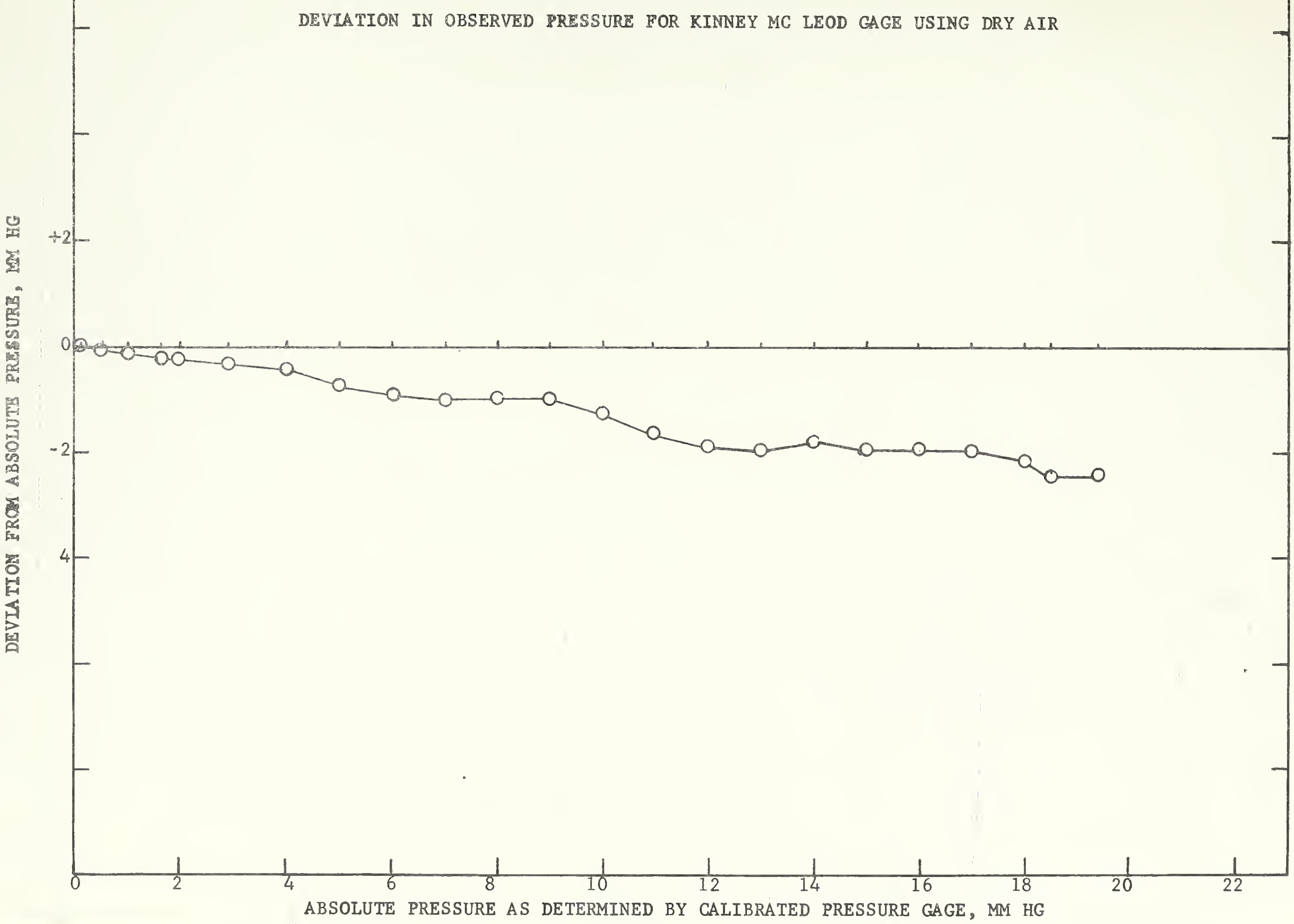


FIGURE 40



REPEATABILITY OF DEVIATION IN OBSERVED PRESSURE FOR TWO GAGES USING NITROGEN
HASTINGS THERMOCOUPLE GAGE, 1ST OBSERVATION
HASTINGS THERMOCOUPLE GAGE, 2ND OBSERVATION
KINNEY MC LEOD GAGE, 1ST OBSERVATION
KINNEY MC LEOD GAGE, 2ND OBSERVATION
WALLACE & TIERNAN ANEROID GAGE, OBSERVED READINGS
DEVIATION FROM ABSOLUTE PRESSURE, MM HG
6
4
+2
0
-2
4
0
2
4
6
8
10
12
14
16
18
20
22
ABSOLUTE PRESSURE AS DETERMINED BY CALIBRATED PRESSURE GAGE, MM HG



DEVIATION IN OBSERVED PRESSURE FOR KINNEY MC LEOD GAGE USING DRY AIR
DEVIATION FROM ABSOLUTE PRESSURE, MM HG
+2
0
-2
4
0
2
4
6
8
10
12
14
16
18
20
22
ABSOLUTE PRESSURE AS DETERMINED BY CALIBRATED PRESSURE GAGE, MM HG

FIGURE 42

DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS