GENERAL
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PRELIMINARY VACUUM OUTGASSING STUDY FOR CATHODE-RAY TUBES

by

D. J. Santeler

Report No. 57GL211 June 18, 1957

GENERAL ELECTRIC

GL-213A (rev.) 9-56

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INTRODUCTION

In the manufacture of Cathode-Ray Tubes, it is required that a high degree of vacuum be established in the tube envelope. It is insufficient to merely pump the gas in the gaseous space out of the tube, as large quantities of gas still reside in the materials and on their surfaces. The removal of this gas is done in the outgassing process. Many pre-exhaust manufacturing processes can affect the amount of this type of gas which must be removed. For example, different types of black paint used in the tube can have different temperature dependent decompositions, the type and amount of lacquer used in the aluminizing process can vary the outgassing, variations in aluminizing thickness may affect the rate at which gaseous products of the lacquer decomposition can escape. In addition, there are other process variables such as the concentration of the hydrofluoric acid wash, the humidity and temperature of the bakeout, pretreatment of various metalic components, and oil contamination of components due to handling.

Regardless of the source of the gas, most of it must be removed at the exhaust station prior to sealing off the tube. This requires vacuum and heat. A number of questions then arise.

What is the most economical combination of temperature, pumping speed, exhaust tubulation, and time to produce a good product?

If outgassing is the limiting feature rather than evacuation, what components in the tube are the major contributors to this outgassing?

Since outgassing is extremely temperature dependent and in view of the fact that the bulb is operated relatively cool and contains a getter, what minimum temperature is required during exhaust such that the getter can maintain the required pressure in the tube while keeping up to the outgassing under the most severe operating conditions?

Can the exhaust process be reduced or the tube life improved by changing materials, their treatment or other pre-exhaust processes?

It was proposed that the new techniques of vacuum process evaluation described in TIS Report No. 57GL210 should be able to assist in answering these questions. Specifically, by employing this technique, it should be possible to determine what outgassing is occurring throughout the exhaust cycle. The relation between the observed outgassing half life and the theoretical exhaust half life would show weather the process was pump limited, tubulation limited, or outgassing limited. If outgassing is the limiting part of the process, then the source of the outgassing can be traced out by checking separate components in the Lab and determining their outgassing characteristics. This is feasible because the total outgassing must be a summation of all the separate sources plus any interaction. In this manner, the variables in the process can be checked out to determine their effect on the exhaust cycle and the proper balance of control could be established. Likewise, once the process variables were evaluated, the technique could be used to aid in establishing the optimum combination of pump speed, time cycle, temperature and tubulation for exhaust. A final application involves the use of process evaluation for trouble shooting. Once a process is established and in operation, a reference curve of the outgassing during exhaust is taken. If then, at a later date, the process begins to fail due to an unknown change in the manufacturing process, a pump down curve can be taken, converted to outgassing, and compared to the reference curve. From past knowledge of the outgassing characteristics of different components and from observing the time at which a deviation from the reference is observed, it should be possible to determine what components or materials could be contributing to the change in the outgassing. This could also be used to check the performance of the pumping system, as each type of failure such as diffusion pump, roughing pumps, leakage, etc., would have a different affect on the outgassing curve. If instrumentation could readily be connected to the exhaust buggies, then when a given buggy produced two bad tubes in a row, a pressure curve could be taken on the following run and the maintenance requirements determined. In many instances, it might be possible to make minor repairs right on the line rather than removing the buggy.

While the above situations appear to be highly desirable, a number of questions can be raised as to weather the technique can produce these answers in view of the complexity of both the equipment and the outgassing sources. For this reason, a preliminary test was made. One day was spent in reference calibration of a particular buggy, and one day was spent taking data on the line. No specific answers as to the outgassing process were expected, rather it was desired to see if the technique would produce outgassing curves which would correlate with one another. It was a second intention to determine what problems might exist in a complete outgassing study.

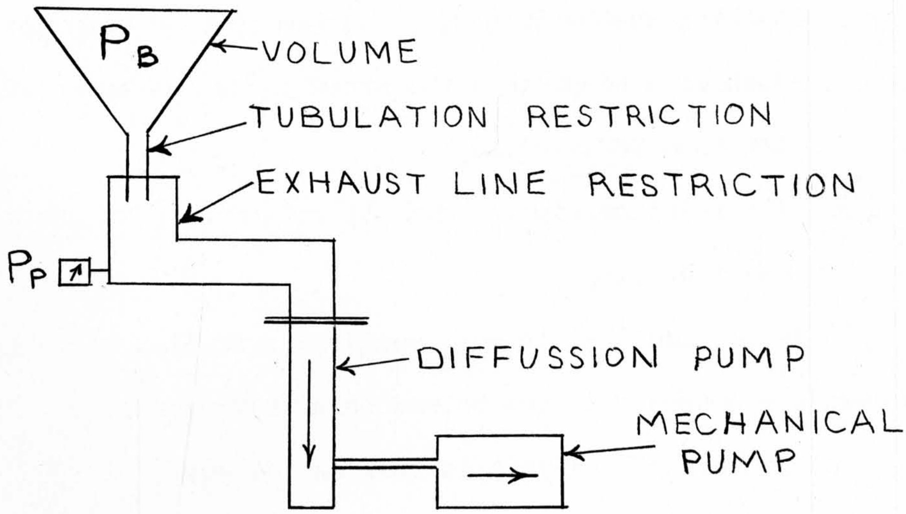
SUMMARY

Tests were made on seven different bulbs. The outgassing curves showed good correlation despite the large number of problems which occurred. In future tests, improved instrumentation will be required. A new technique of pressure amplification looks very promising for such an application. In future tests, it will also be necessary to determine the gas and bulb temperatures throughout the exhaust process.

With improved instrumentation and temperature measurement, the technique of vacuum process evaluation should prove to be a valuable tool in investigating and understanding both the exhaust process and the various factors which can affect it.

VACUUM PROCESS EVALUATION

Before proceeding with a detailed discussion of the tests and their results, it would be well to review briefly the technique of vacuum process evaluation. A detailed description will be found in TIS Report No. 57GL210. Details of the programming of the 650 IBM computer for process evaluation, data handling facilities, and special services which can be offered for outgassing studies, will be published in the near future.



Consider the above sketch in which is shown the volume to be outgassed, a pumping system, and interconnecting restrictions between the two. Three pieces of information are required:

1. The relationship between pressure P_B in the volume to be outgassed and the pressure P_P at some known point in the pumping system or interconnecting restrictions. This must be known over the entire range of pressures for which the

study is to be made. It can be obtained either from a knowledge of the interconnecting restrictions and the speed of the pumping system or it can be obtained by placing calibrated gages at both positions and directly measuring the pressures.

2. The relationship between the pressure in the volume and the gas flow rate out of the volume in the absence of all outgassing. This can be obtained mathematically or from a graphical solution if the geometry of the restrictions and the speed of the pumping system is known. It can also be obtained from the pump down of a completely outgassed volume of known size and with the same restrictions.

3. The relationship between the pressure P_P in the vacuum system and the time.

It is assumed that in most outgassing studies it is impossible to directly measure the pressure in the volume being outgassed.

The process of analysis is then as follows:

a. Convert from the pressure measured in the system to the actual pressure existing in the volume.

b. From the slope of the converted pressure-time curve and the volume determine the instantaneous actual flow rate of gas out of the volume as a function of time.

c. From the pressure existing in the volume at different periods of time determine what the theoretical flow rate out of the volume would have been in the absence of outgassing.

d. The difference between the two flow rates is then directly attributed to the instantaneous outgassing occurring at that period of time. It can be shown on a sound mathematical basis that since the analysis is made on the basis of a rate of change of pressure rather than a time required to reach a given pressure, a constant correction is applied for the additional time required to remove the gas added to the volume from previous outgassing.

e. The process can then be studied by taking different outgassing curves while varying such parameters as the pre-exhaust processes, types of material, temperature cycle, and pumping speed. Predictions can then be made of how further variation of these parameters can affect the process.

In order to simplify the discussion, each test will be presented separately along with any comments, results or conclusions.

MECHANICAL PUMP - GRAPHICAL ANALYSIS

Figure #1 is a graphical analysis of the mechanical pumping system. Because of the shortage of time available for the test and the difficulty of getting a completely outgassed bulb, all analysis were made from this theoretical curve. As will be evident from the test runs, this curve is a true picture of the relationship between the pressure (on the lower scale) and the thruput (on the right margin).

Three curves are drawn on this graph, one for the pump, one for the exhaust tubulation and one for the net system comprising the pump plus the tubulation. If a value of the flow is chosen, then where it intersects the net system curve defines the value of P_B, the pressure in the bulb. Where the flow intersects the pump curve is the corresponding value of the pressure P_P between the pump and the tubulation. We can, therefore, obtain the first two relationships required, directly from this curve. We also note from the curves that above 400 microns the mechanical pump is the limiting item while below 400 microns the tubulation becomes the limiting factor. Since it requires approximately 10 minutes to reach 400 microns in the absence of outgassing, the only time which can be saved with a bigger mechanical pump would be that fraction of the 10 minutes equivalent to the speed increase. As an example, a pump of twice the speed would reduce the time to five minutes. However, it is important to note that we are not only after an exhaust, but must consider the outgassing of the tube. If the outgassing is the limiting feature rather than the exhaust, then no over-all process time will be saved by faster pumping. The important feature then will be the temperature to which the bulb is heated.

VACUUM ENGINEERING GRAPH - I FOR SYSTEMS

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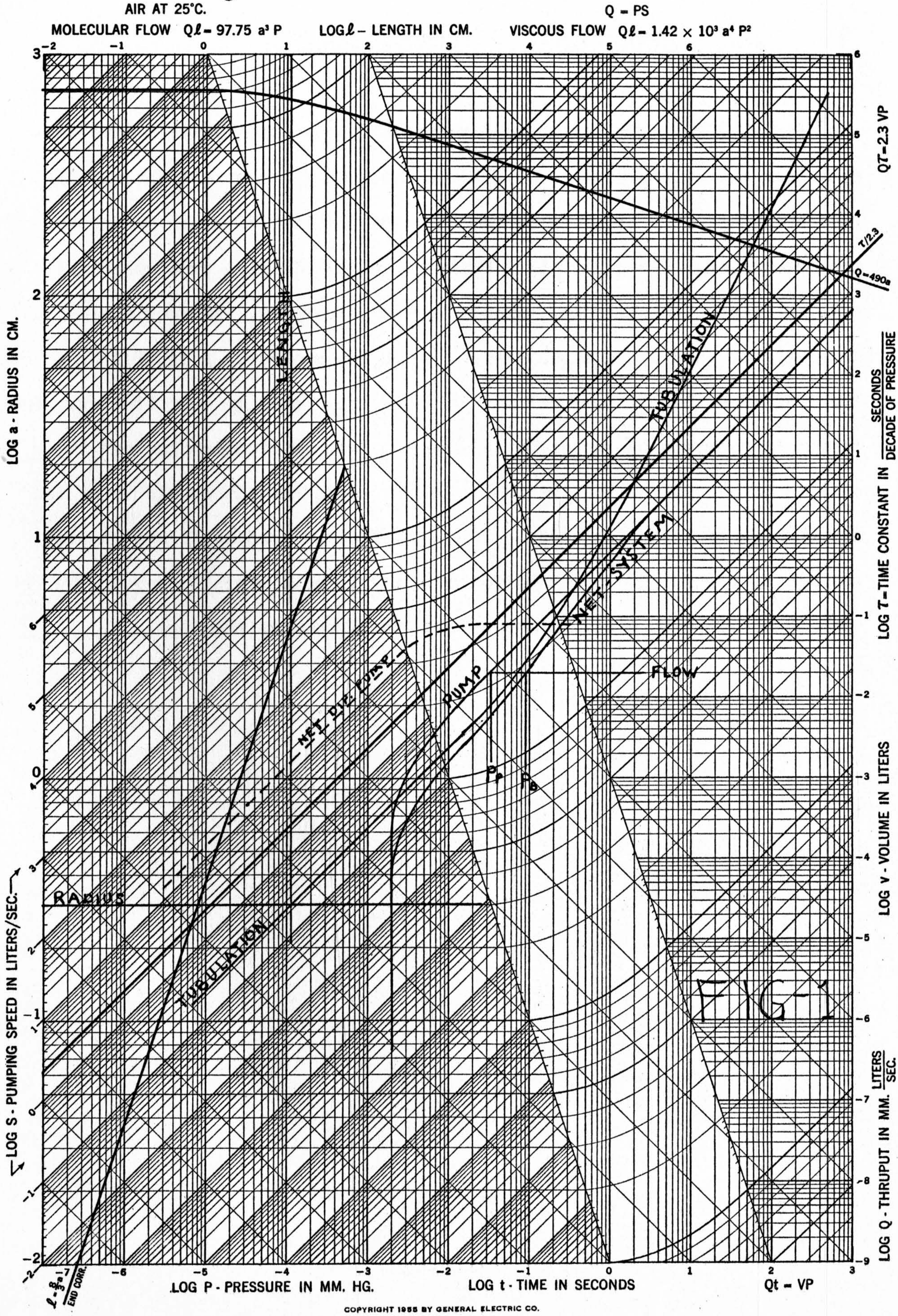

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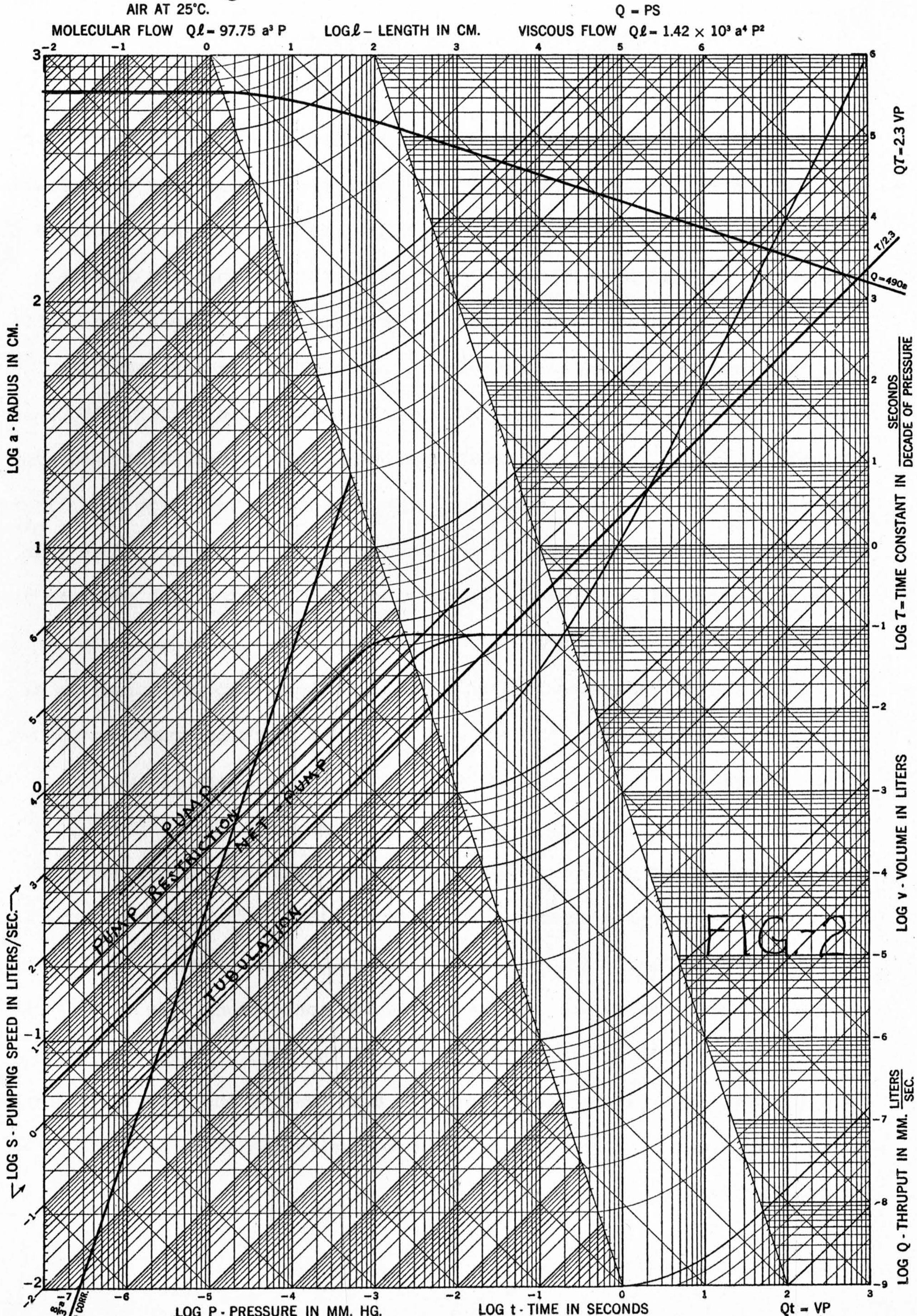
DIFFUSION PUMP - GRAPHICAL ANALYSIS

Figure 2 is a similar curve for the diffusion pump system. Here we note that the pump restrictions between the pump and the port effectively reduce the speed by 5:1. This reduced speed is still 60 times faster than the tubulation. Obviously then, an increase in diffusion pump speed will have no affect on either the exhaust or the outgassing. In fact a considerably smaller pump could easily keep up with the process. A smaller pump has the advantage that it does not need a large fore pump to hold it down. The important criteria of the diffusion pump in this application is that it be capable of a good ultimate vacuum. This suggests that it should be of the three stage fractionating type. The type of fluid used could also be important as regards its contribution to the pressure. This is especially true when trying to evaluate the process from pressure readings.

VACUUM ENGINEERING GRAPH - I FOR SYSTEMS

FN-756-A (3-56)



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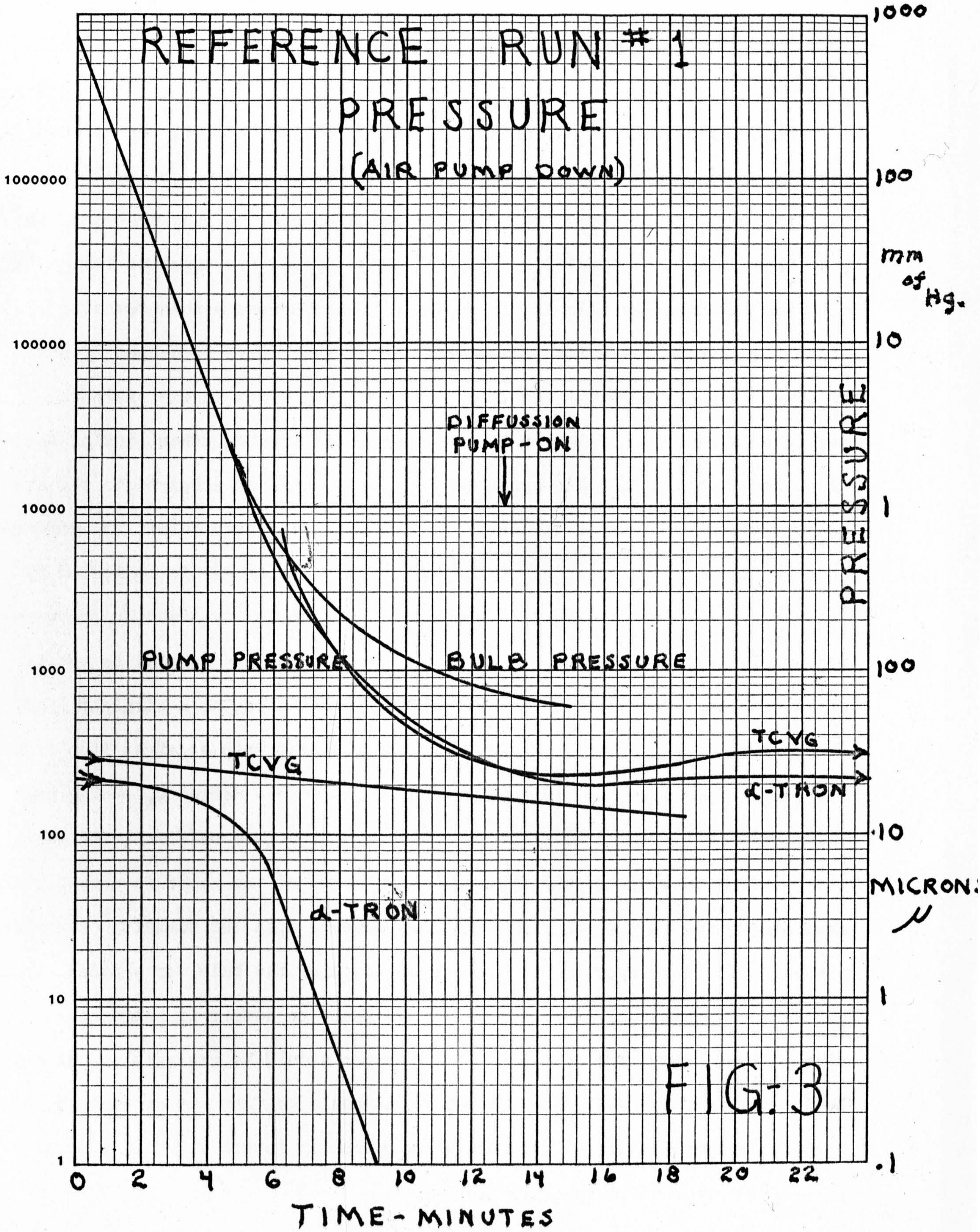
REFERENCE RUN #1 - PRESSURE

In order to evaluate the graphical analysis, an empty cathode-ray tube bulb was placed on the exhaust buggy. An alphatron vacuum gage was mounted at the head of the diffusion pump. The output of this gage was connected to a recorder. A thermocouple vacuum gage was mounted between the diffusion pump and the mechanical pump. Below 200 microns, the two gages agree quite well when only the mechanical pump is being used. In order to evaluate the theoretical curve, it is necessary to have a curve of the actual bulb pressure. Attempts to mount a gage in the bulb-proper and obtain consistent readings were unsuccessful. It was, therefore, necessary to convert from the alphatron pressures measured in the pump to the bulb pressure. Note that above 1 mm, there is essentially no drop across the tubulation and the bulb pressure is the same as the pump pressure.

In the first reference test only the mechanical pump was turned on at the start. The pump down was from room air. The diffusion pump was turned on 13 minutes later. A small rise in pressure on both gages is noted as the oil in the pump warms up and outgasses. The time scale is continued on the left margin. At about 28 minutes the diffusion pump has reached temperature and a rapid fall in the alphatron pressure is noted. The lower pressure limit of the alphatron is .1 micron. Attempts to seal an ion gage to the pumping system were unsuccessful due to leakage of the connections. In view of the short time available and the basic purpose of the test, it was decided to omit the ion gage. It was later observed that most of the outgassing occurs below .1 micron and hence an ion gage or equivalent would be required in any future studies.

MODEL DATE



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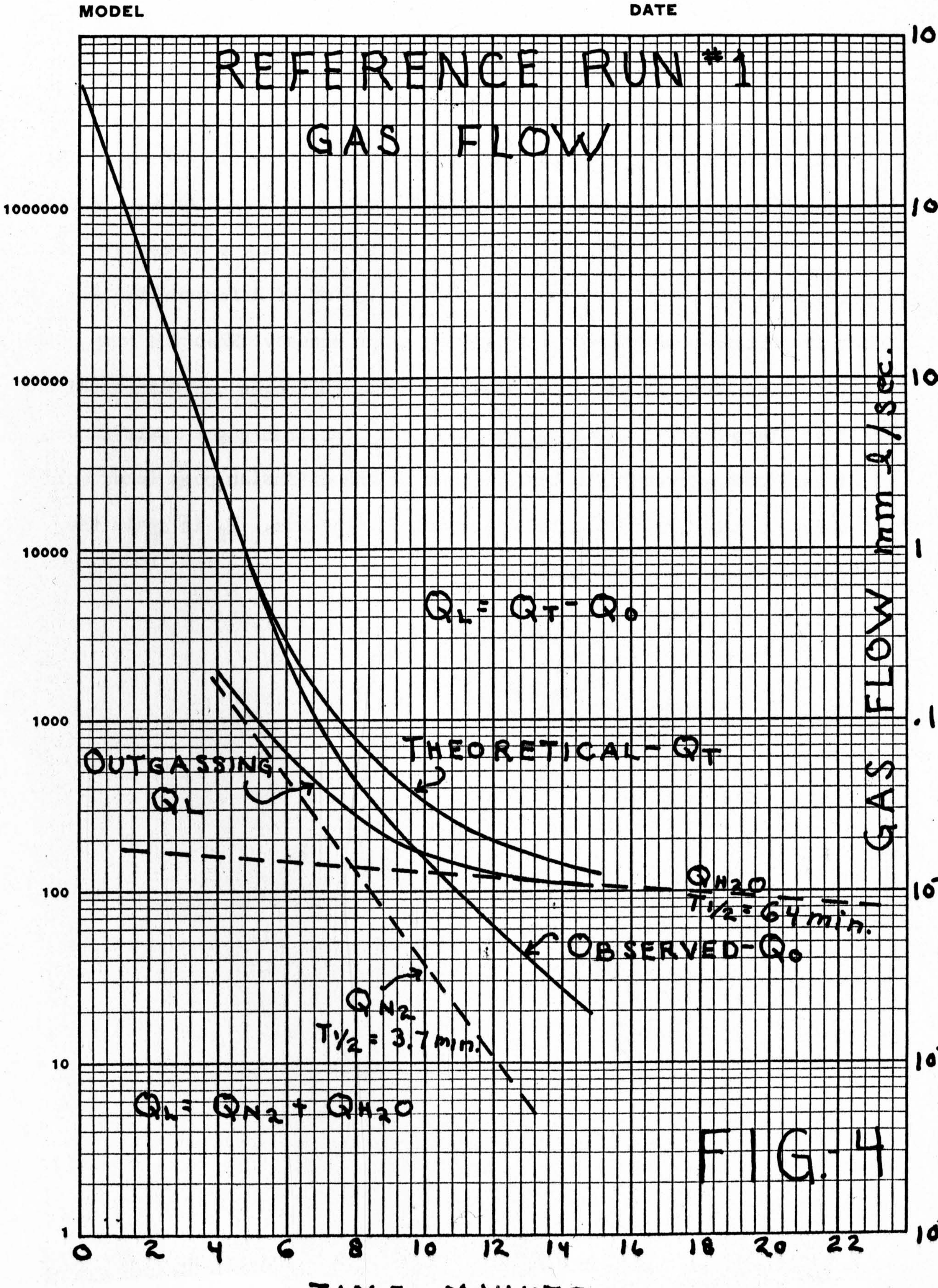
DJS

REFERENCE RUN #1 - GAS FLOW

From the converted bulb pressure readings and the volume, the observed gas flow Q_O was calculated and is shown on Figure 4. The theoretical flow Q_T, obtained directly from the graphical solution and the pump pressure, is also shown. For the first five minutes, these curves are together indicating that the graphical solution is as accurate as the pressure measurements. After five minutes, the two curves begin to spread. This is caused by one of three things: error in the graphical solution, error in the pressure gages, or outgassing of the bulb. Because of the good agreement during the first five minutes when the outgassing would be small as compared to the exhaust, we can pretty much eliminate the first two and assume that the difference is the actual outgassing of the bulb. This difference is indicated by the curve marked outgassing Q_L. Because of the complexity added by the warming up of the diffusion pump, these flow curves were only carried to a time of 15 minutes. However, if we extrapolate the end slope as a straight line, we obtain the dashed curve marked Q_{H_2O}. Subtracting this straight line from the outgassing curve, we obtain the other dashed curve marked Q_{N_2}. The half life, or time to reduce the flow by a factor of two is consistent with past observations in other vacuum systems. The source of the water is probably from adsorption on the surfaces. It then depends upon the humidity or partial pressure of water vapor in the atmosphere to which the bulb was exposed. The partial outgassing curve marked Q_{N_2} always seems to appear in outgassing studies even though the adsorption of nitrogen should be negligible. It may be due in part to a diffusion process or it could be flow out of small cracks or surface imperfections. This is being currently investigated in the GEL as part of the over-all outgassing program.


MODEL
DATE
REFERENCE RUN #1
GAS FLOW
$Q_L = Q_T - Q_O$
THEORETICAL - Q_T
OUTGASSING Q_L
Q_{H_2O}
$T_{1/2} = 64$ min.
OBSERVED - Q_O
Q_{N_2}
$T_{1/2} = 3.7$ min.
$Q_L = Q_{N_2} + Q_{H_2O}$
FIG. 4
1000000
100000
10000
1000
100
10
1
10^3
10^2
10
1
.1
10^{-2}
10^{-3}
10^{-4}
GAS FLOW mm ℓ/sec.
0 2 4 6 8 10 12 14 16 18 20 22
TIME - MINUTES

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D.J.S.

REFERENCE RUN #2 - PRESSURE

The second reference curve taken is shown in Figure 5. For this run, both the diffussion pump and the mechanical pump were turned on at the same time. It was intended that the pump down be taken from one atmosphere of dry nitrogen admitted to the bulb at the conclusion of Reference Run #1. After the nitrogen was added, the valve was not closed. When the pump down started, some room air was drawn into the bulb. Nitrogen was readmitted and the test started again. The thermocouple and alphatron gages again showed relatively good agreement to the point where the diffusion pump takes hold and causes a rapid reduction in the alphatron pressure. P_B is again the converted pressure in the bulb.

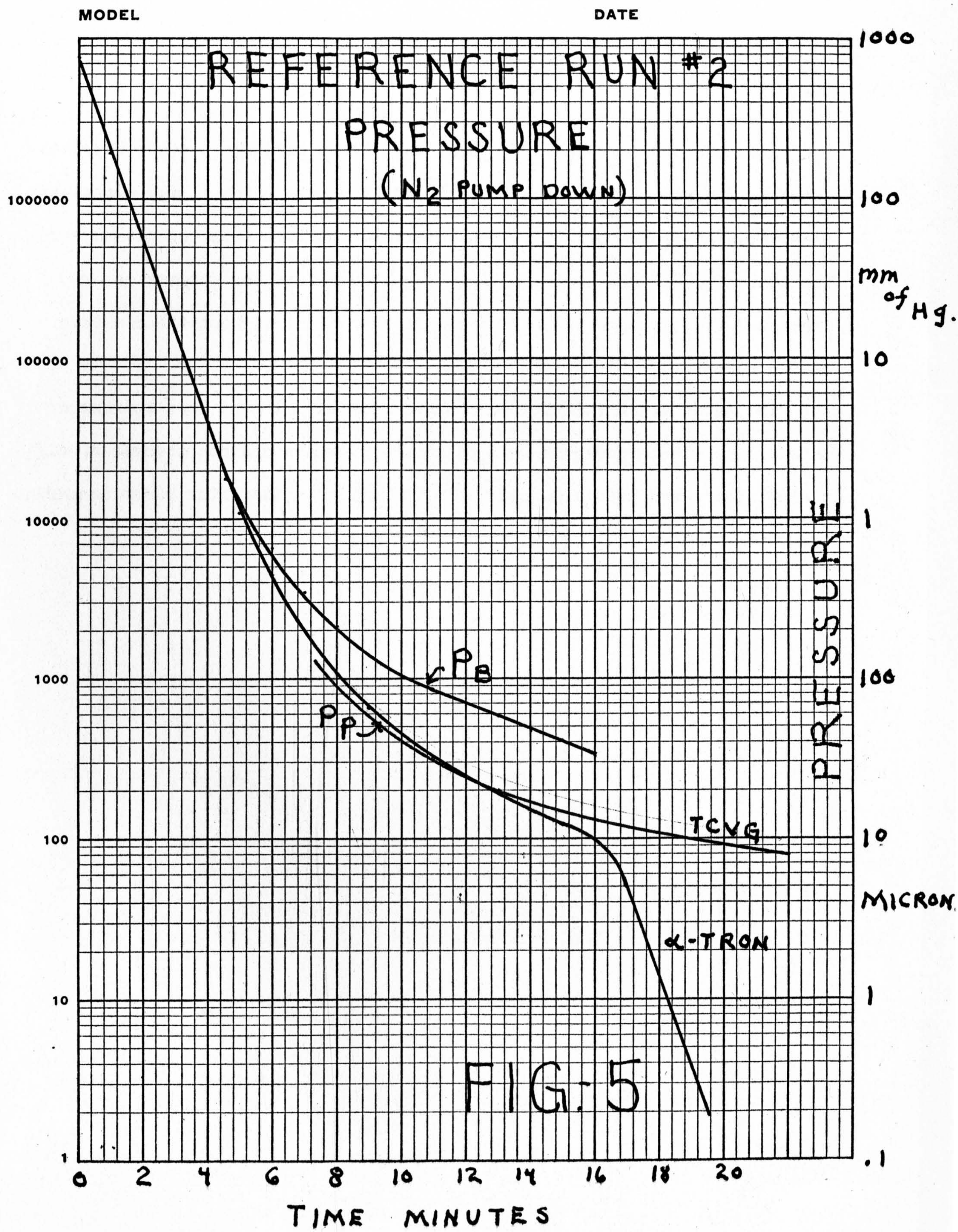
MODEL
DATE
REFERENCE RUN #2
PRESSURE
(N2 PUMP DOWN)
1000000
100000
10000
1000
100
10
1
1000
100
mm of Hg.
10
1
100
10
MICRON
1
.1
PB
PP
TCVG
α-TRON
PRESSURE
0
2
4
6
8
10
12
14
16
18
20
TIME MINUTES

FIG. 5

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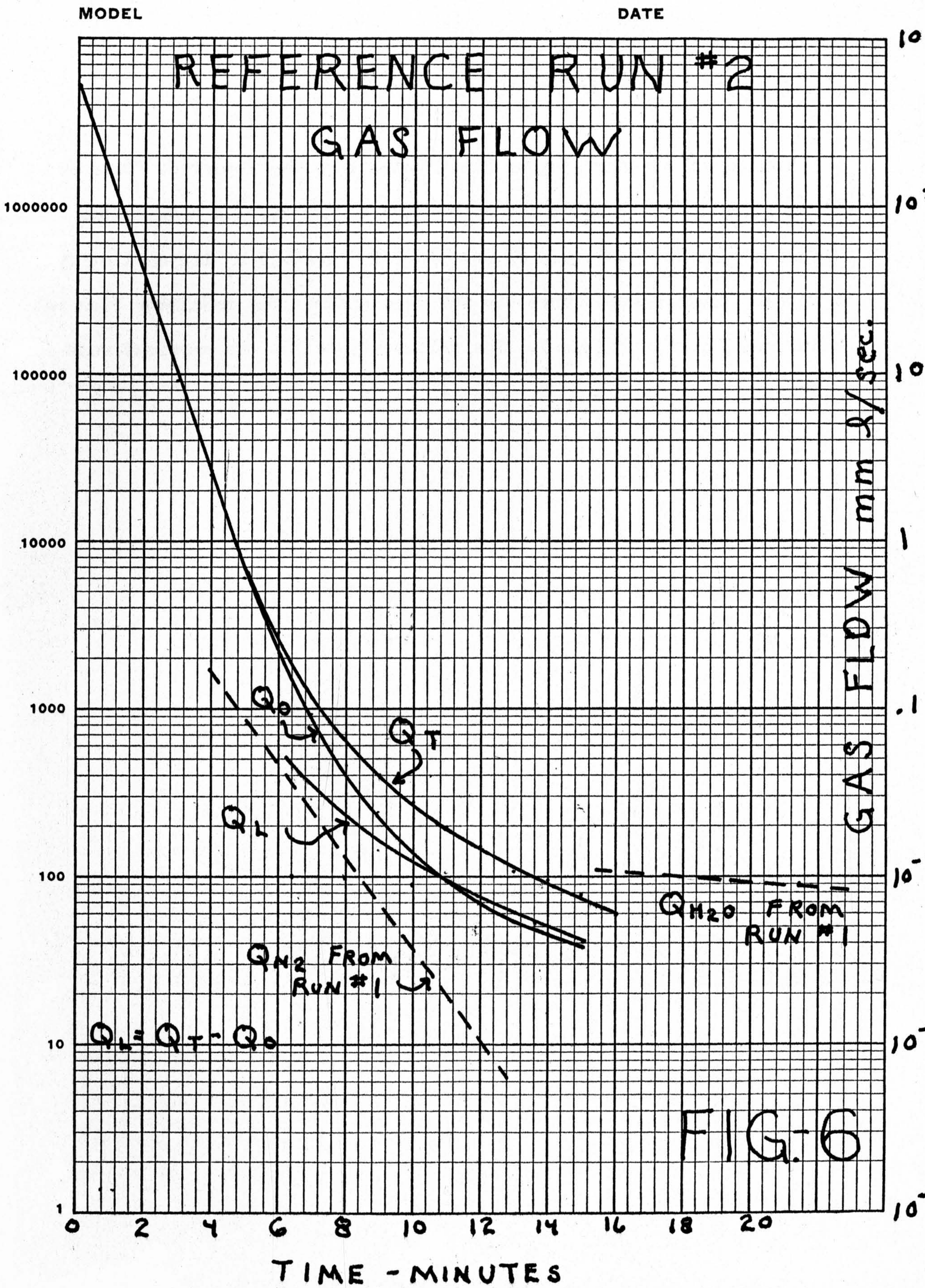
D/S.

REFERENCE RUN #2 - GAS FLOW

From the pressure data, the two flow curves were again constructed as shown in Figure 6. Q_T is the theoretical flow rate which should exist at each value of pressure. Q_O is the observed flow rate from the pressure reduction. The difference between these two curves is the outgassing or leakage Q_L. This same nomenclature will be used throughout the remainder of the report.

The water vapor and nitrogen curves from Run #1 have been redrawn on this graph. It is apparent that while the nitrogen has not changed significantly, there has been a considerable reduction in the water vapor component as would be expected.



MODEL
DATE
REFERENCE RUN #2
GAS FLOW
1000000
100000
10000
1000
100
10
1
10^3
10^2
10
1
.1
10^{-2}
10^{-3}
10^{-4}
GAS FLOW mm ℓ/sec.
Q_0
Q_T
Q_L
Q_{N_2} FROM RUN #1
Q_{H_2O} FROM RUN #1
$Q_L = Q_T - Q_0$
FIG. 6
0
2
4
6
8
10
12
14
16
18
20
TIME - MINUTES

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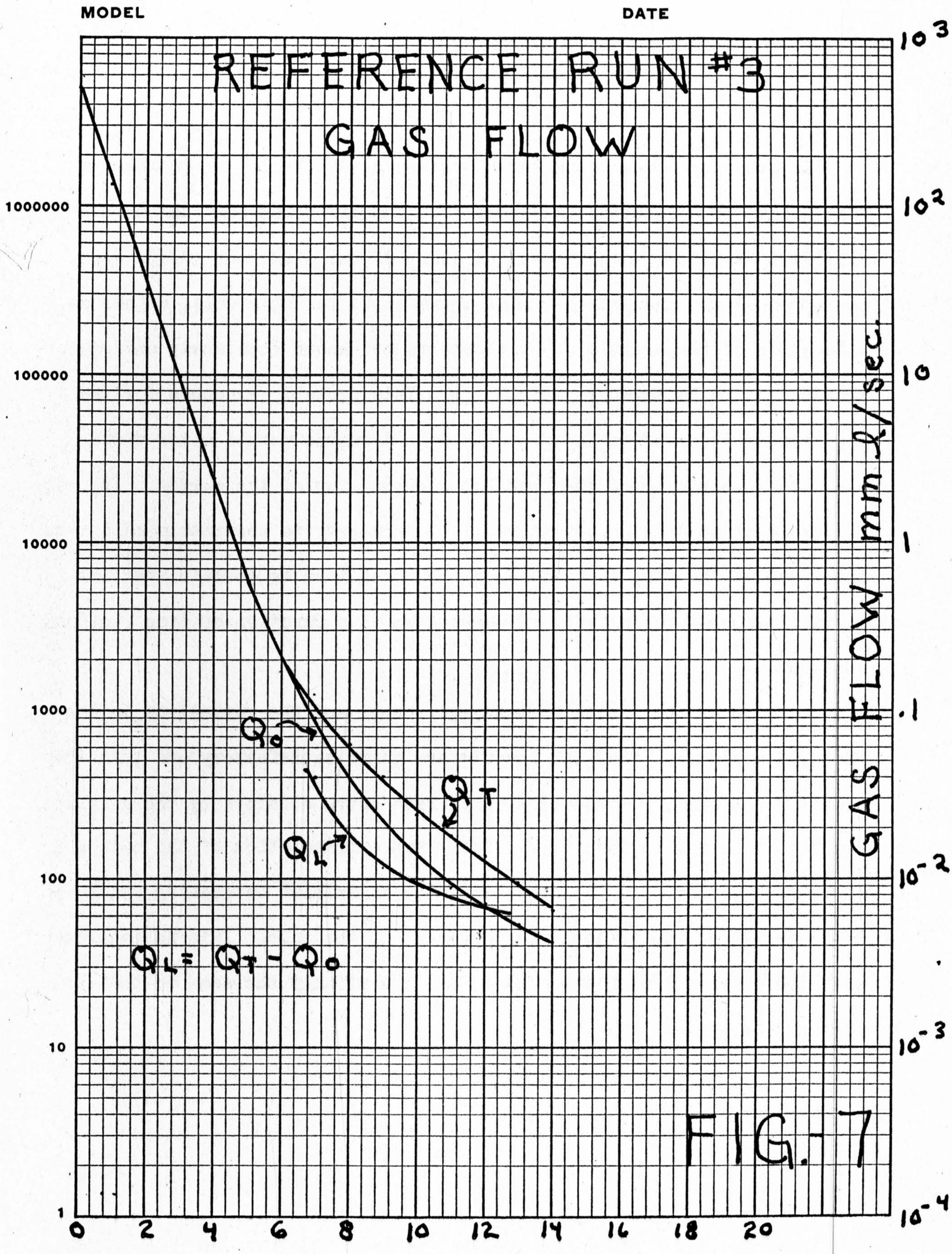
D.L.S.

REFERENCE RUN #3 - GAS FLOW

Because of the air leak on Run #2, the test was repeated. Nitrogen was admitted to the bulb at the completion of Run #2. As soon as the diffusion pump was cool, Run #3 was started. Because of its similarity to Run #2, the pressure curve has not been shown. The resulting flow rate curves are given in Figure 7. The similarity to the two previous runs is evident.



MODEL
DATE
REFERENCE RUN #3
GAS FLOW
1000000
100000
10000
1000
100
10
1
10^3
10^2
10
1
.1
10^{-2}
10^{-3}
10^{-4}
GAS FLOW mm ℓ/sec.
Q_o
Q_T
Q_L
$Q_L = Q_T - Q_o$
0 2 4 6 8 10 12 14 16 18 20
TIME - MINUTES

FIG. 7

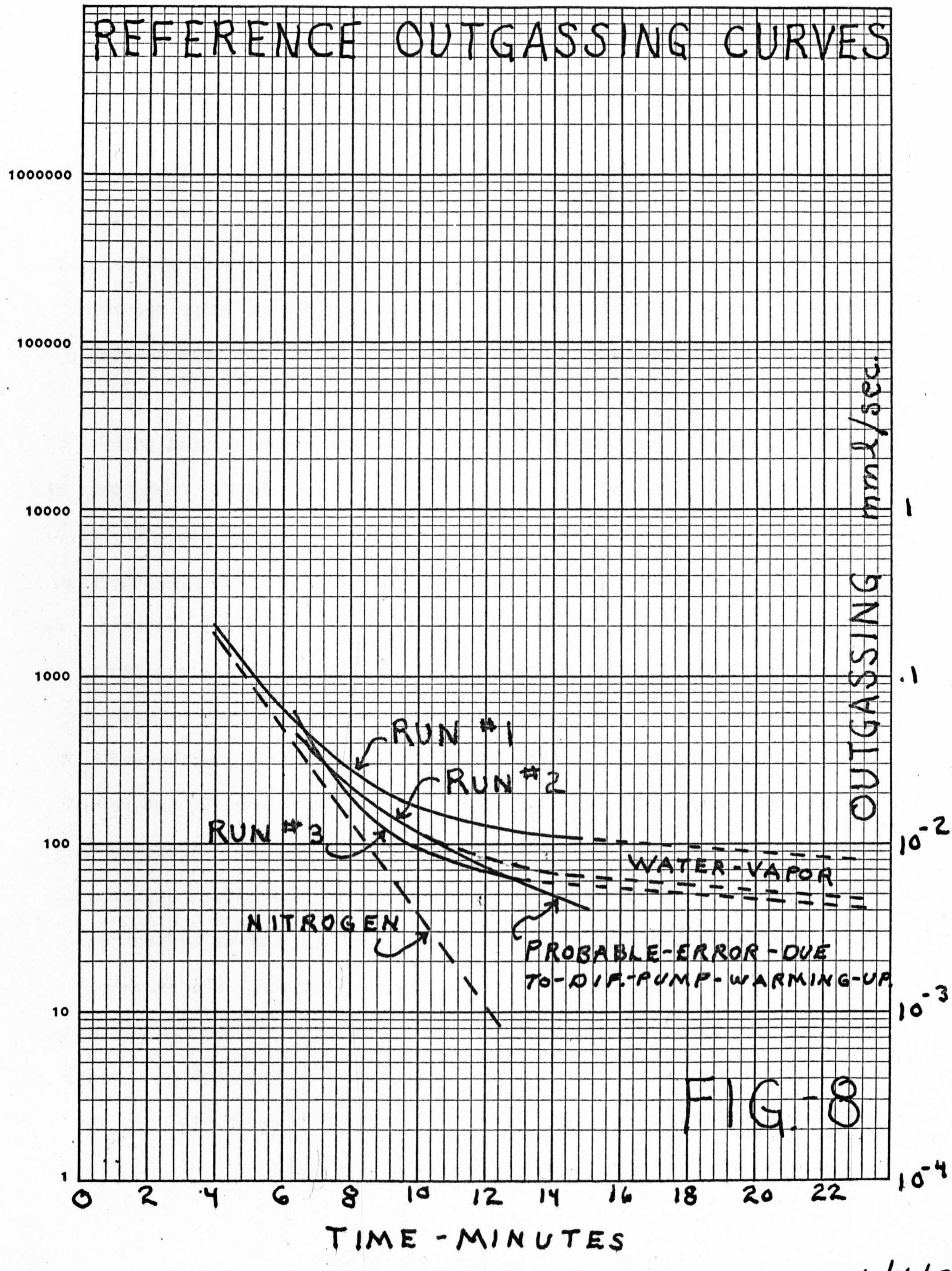
1/4/57
D/S.

REFERENCE OUTGASSING CURVES

In order to compare the three test runs, the resulting outgassing curves have been combined on Figure #8. The diffusion pump had been at different degrees of cooling at the start of the different runs. Also, the speed of the pump at the point where it is taking a hold, either as a function of temperature or pressure, is not known accurately enough for proper data to be taken in this range. This probably accounts for the discrepancy observed on Run #2. The dotted curves marked water vapor are only an estimate of the probable continuation of the curves. In order to take data in this range, it would be necessary to accurately calibrate the speed of the pump as it is warming up and then be certain that its initial temperature and rate of warming up as a function of time remained constant.

In view of the limits of the gage, pump, and the variations in the tests, I would feel that the results are quite satisfactory and that they properly confirm the theoretical flow rate curve obtained by the graphical analysis as shown in Figure #1. Note that extrapolation of the nitrogen curve back to time equals zero, indicates an initial outgassing which is less than 1% of the initial flow rate out of the bulb. This is consistent with the observation that Q_O and Q_T are essentially the same in the early part of the cycle.

MODEL DATE



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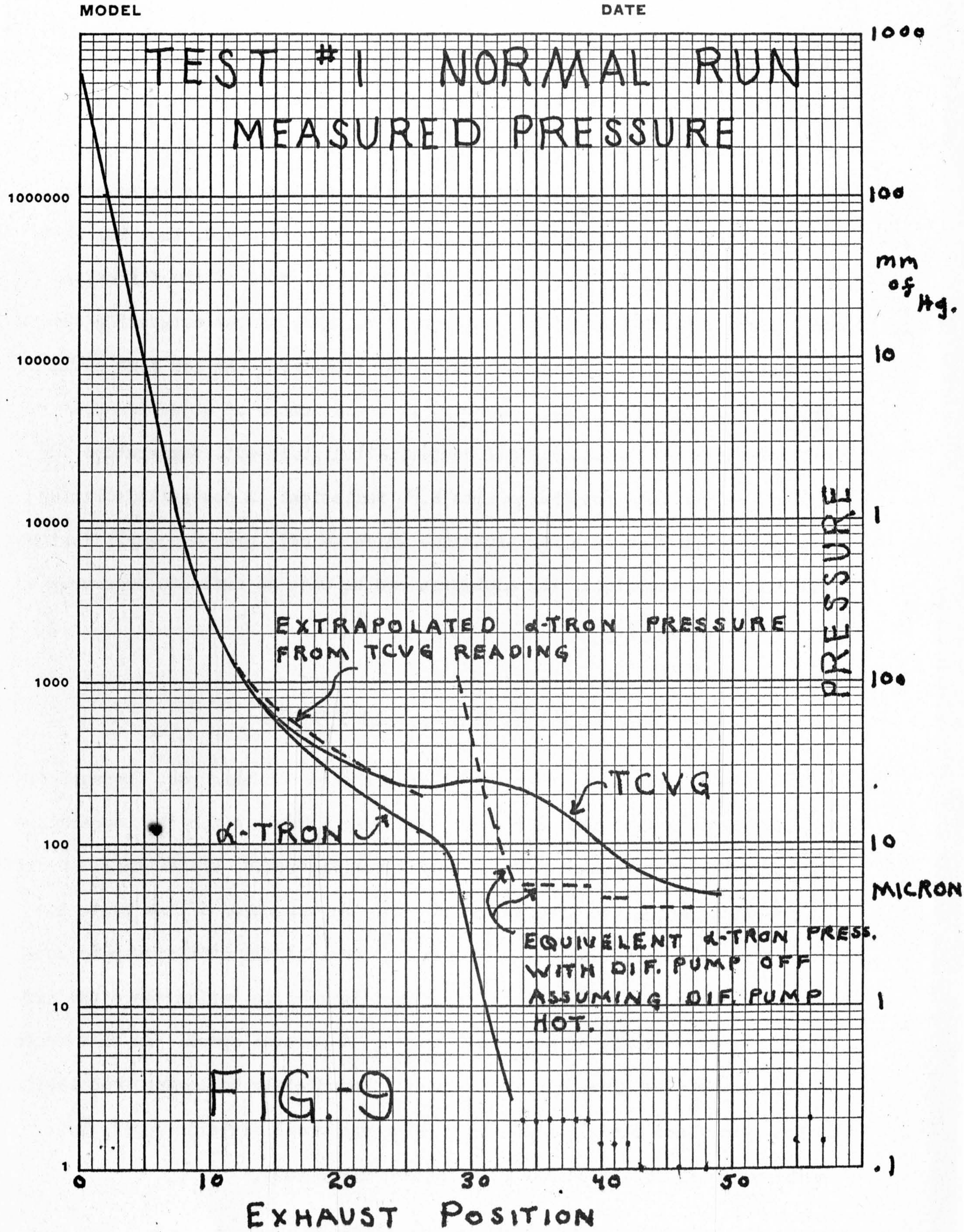
DJS

TEST #1 NORMAL RUN - MEASURED PRESSURE

The exhaust buggy on which the reference tests were made was then placed in position on the exhaust system. The adjacent position was left free to contain the vacuum gages and recorder. On the first few runs, everything behaved properly; however, some form of electrical pickup shortly developed on the recorder. This resulted in a wide band being recorded. As a result, it was necessary to take visual readings of the gage at each position on the exhaust system.

Figure #9 is the data obtained on the first tube exhausted after allowing the buggy to make one complete circuit on blankoff. Note that the time scale on the lower margin has been changed to exhaust position. Position #7 is the first position in the oven, and hence it begins the high temperature outgassing. The buggy is in each position for 36 seconds. At position zero, the mechanical pump is turned on and power is applied to the diffusion pump heater. On this graph, we note a discrepancy between the thermocouple and alphatron gages prior to the rapid fall in pressure. The dotted curve indicates what the alphatron should have read as determined from the TCVG pressure and a calibration obtained from the reference test. This discrepancy is probably caused by the temperature effect on both the flow rate and gage calibration. This presents the first major problem. Several methods could be used to correct this situation. The graphical solution could be drawn for a family of temperatures and the actual temperature of the gas coming from the tubulation could be measured as a function of time. The gage would also have to be temperature calibrated and the pressure increase with temperature inside the bulb determined. An easier


MODEL
DATE
TEST #1 NORMAL RUN
MEASURED PRESSURE
1000000
100000
10000
1000
100
10
1
1000
100
mm of Hg.
10
1
PRESSURE
100
10
MICRON
1
.1
EXTRAPOLATED α-TRON PRESSURE FROM TCVG READING
TCVG
α-TRON
EQUIVELENT α-TRON PRESS. WITH DIF. PUMP OFF ASSUMING DIF. PUMP HOT.
FIG. 9
0
10
20
30
40
50
EXHAUST POSITION

1/10/57
DJS.

solution would be to do the reference calibration on the exhaust system with a completely outgassed bulb so as to simulate all temperature effects. A calibration between the pump pressure and the bulb pressure is still required. This calibration is also temperature dependent and hence time dependent.

A second major problem is also indicated on this graph, that is, what type of gage should be used. Because of the high speed of the diffusion pump relative to the existing outgassing rate, most of the outgassing occurs at pressures too low to be indicated by the alphatron. An ion gage could be used for part of this range. However, it has a number of objectionable features--long time constant, oil contamination, burn-out, temperature dependent, and calibration change with R.F. radiation. A potential solution to this problem lies in a new technique which we call pressure amplification. Utilizing this technique, the alphatron can be made to indicate pressures as low as 10^{-6} mm of Hg.

TEST #1 NORMAL RUN - BULB PRESSURE

Figure #10 shows the converted bulb pressure for this run. Because of the exploratory nature of this series of tests, no allowance for the temperature effect on the gas flow was made. Recall from Figures #1 and #2 that two different graphical solutions are available. For the beginning of the test, the mechanical pump conversion is used while at the end the diffusion pump conversion is proper. Note that there is an intermediate region where the diffusion pump is warming up and hence pumping at partial speed. In this region, neither conversion gives a proper answer. Immediately following this region is the area where the alphatron is reading one small division on its most sensitive scale and hence has its greatest inaccuracy.

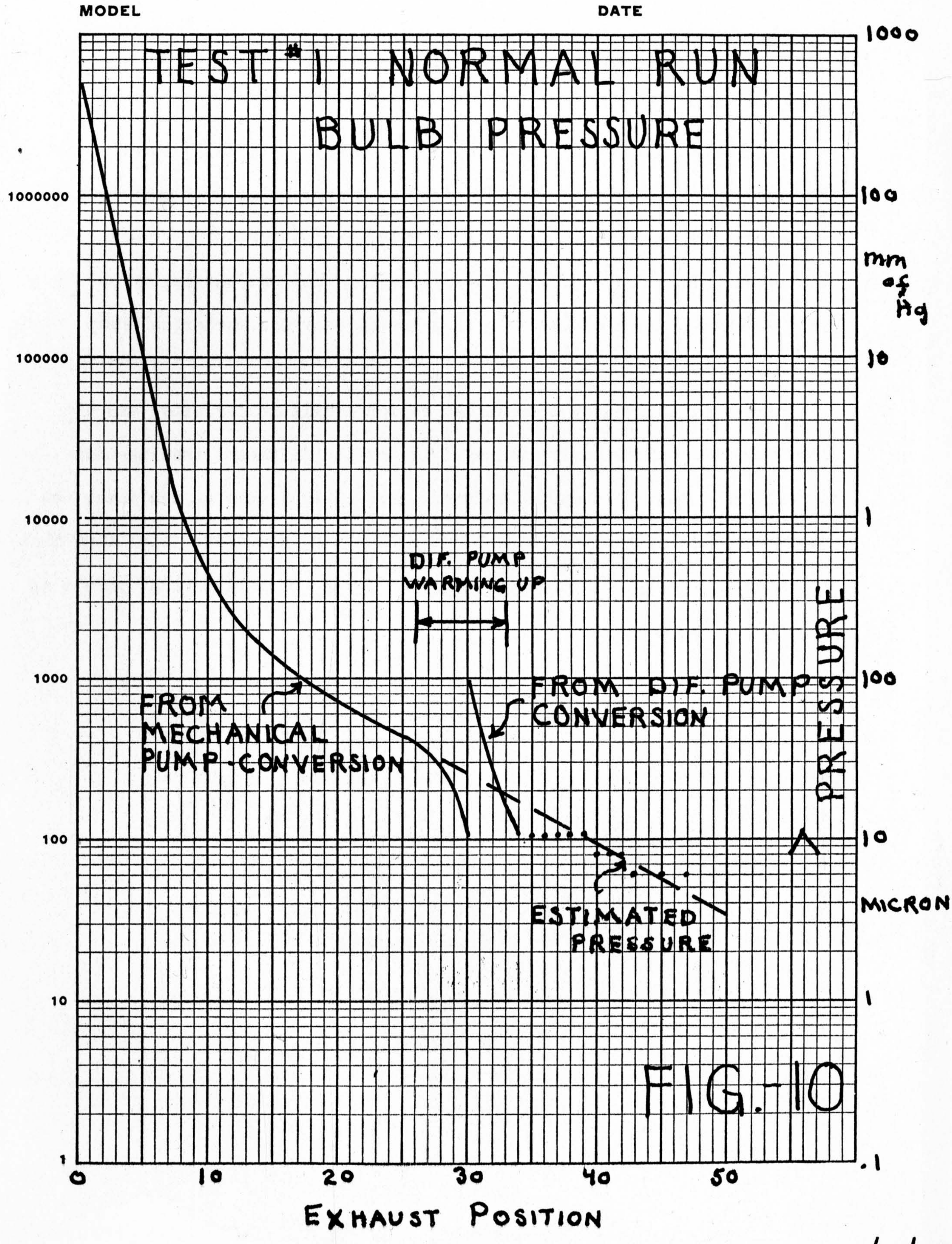


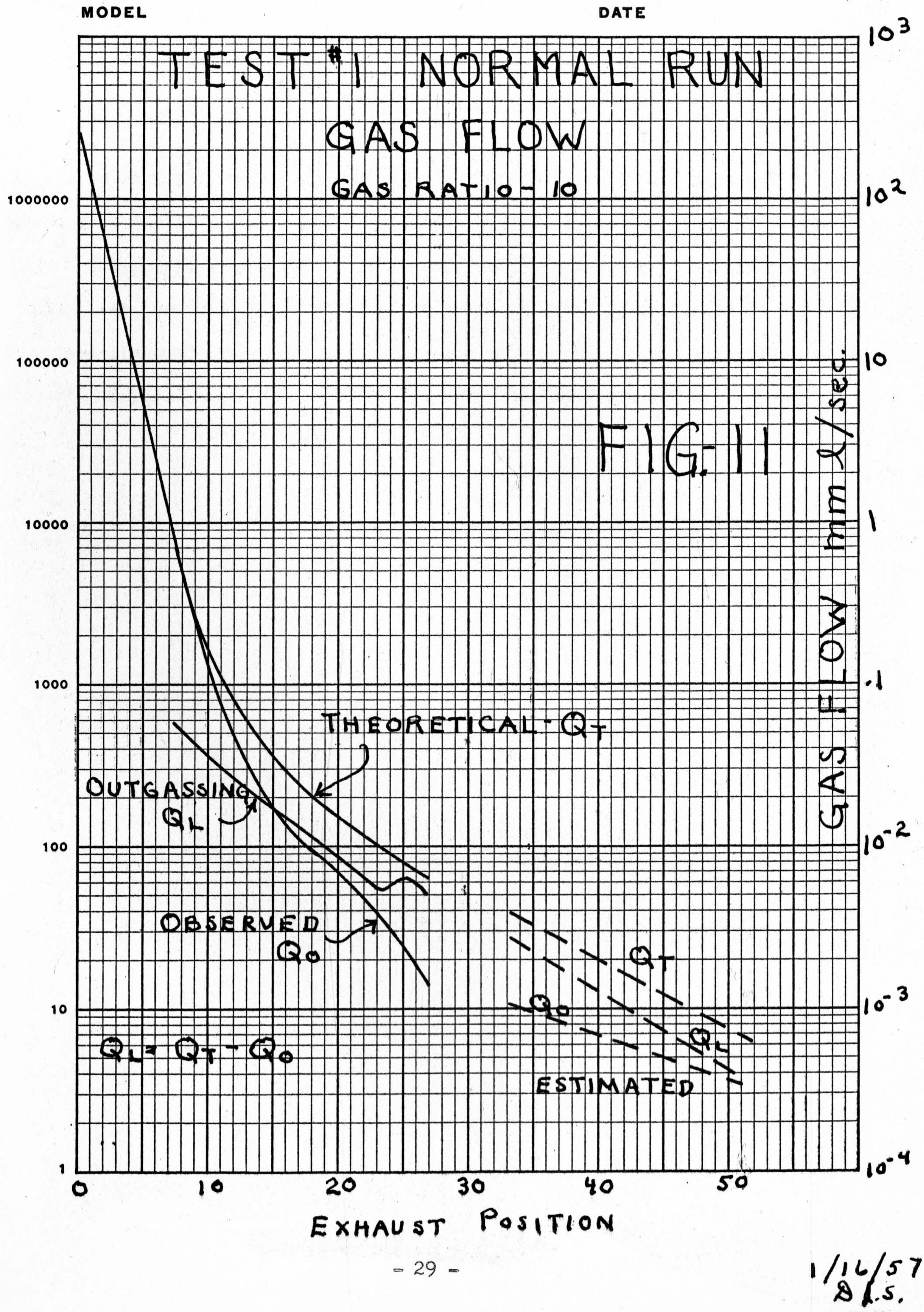
FIG. 10

1/10/57
D/S

TEST #1 NORMAL RUN - GAS FLOW

Figure #11 shows the resulting gas flows and outgassing calculated from the previous data. Where the diffusion pump is at full speed and the alphatron at its extreme lower sensitivity, the curves are dotted and marked estimated. The dead band where the diffusion pump was warming up has been left blank. In most of the following tests, only the mechanical pump region is reported on.

The outgassing over the limited region available for study and with the limitations previously discussed is not too different than that observed for a cold bulb on the reference test. Note that on the first few positions, the outgassing is such a small percentage of the total flow that it cannot properly be evaluated. This is a common problem which exists on all outgassing studies.


MODEL
DATE
TEST #1 NORMAL RUN
GAS FLOW
GAS RATIO - 10
FIG. 11
THEORETICAL - Q_T
OUTGASSING Q_L
OBSERVED Q_O
Q_T
Q_O
Q_L
ESTIMATED
$Q_L = Q_T - Q_O$
1000000
100000
10000
1000
100
10
1
10^3
10^2
10
1
.1
10^{-2}
10^{-3}
10^{-4}
GAS FLOW mm l/sec.
0
10
20
30
40
50
EXHAUST POSITION
1/16/57
D.L.S.

TEST #2 NORMAL RUN - GAS FLOW

The normal test was repeated to determine the reproducibility of the test. The pressure curve which was very similar to that obtained in Test #1 is not given. The resulting flow rate curves are shown in Figure #12. The order of magnitude of the outgassing curve is the same; however, the shape is different. This will be more evident on a later graph where all the outgassing curves are combined. The gas ratio of this tube was not determined.

MODEL DATE

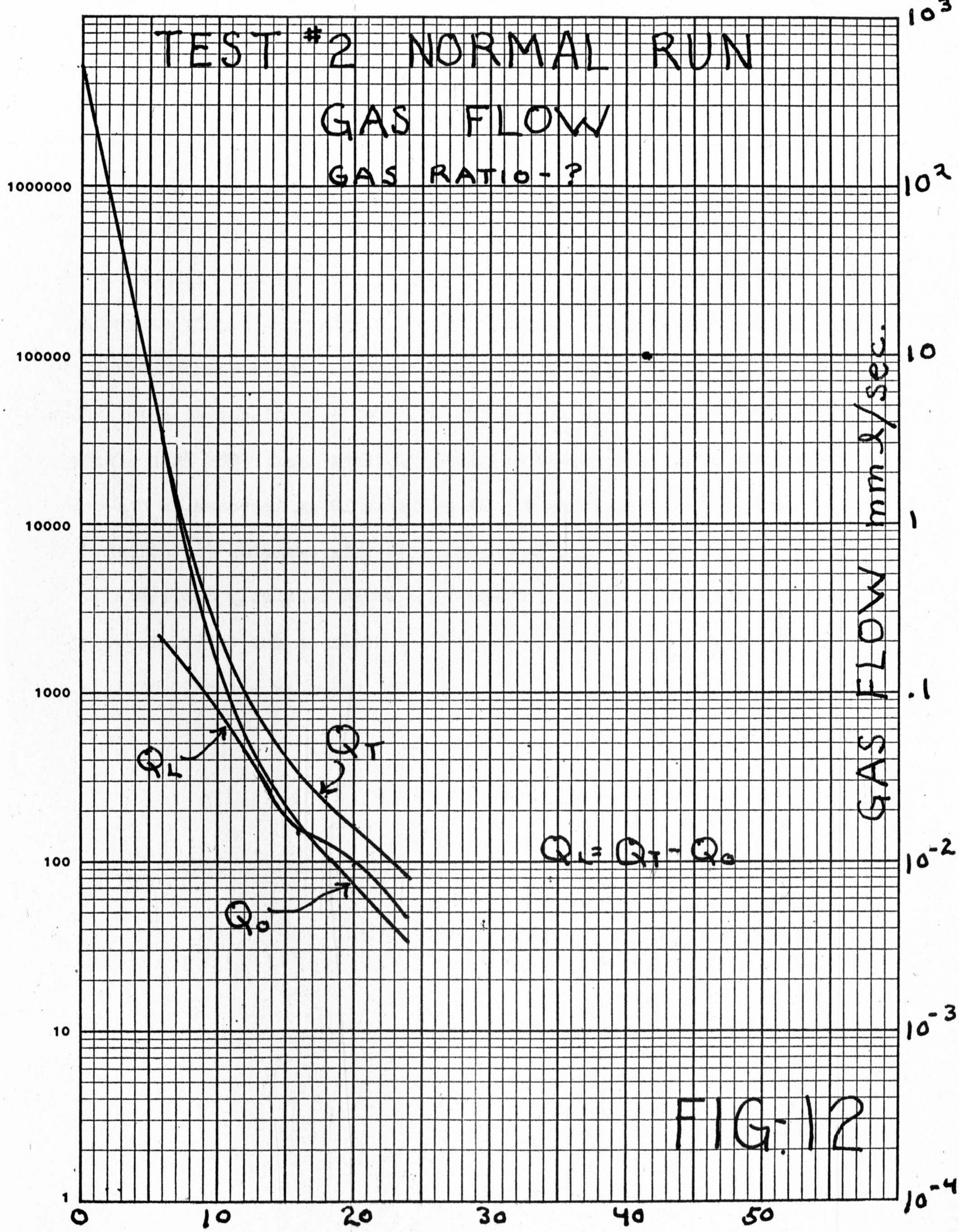


FIG. 12

1/16/57
D.J.S.

TEST #3 PRE-PUMP - GAS FLOW

In order to extend the range over which outgassing could be observed, a bulb was placed on the buggy and pre-pumped. In this way, the outgassing of the bulb when it enters the furnace would be a large percentage of the total flow and hence could be more accurately determined. Because of the limitations of the exhaust system, the pre-pumping could only be started four positions in advance of the normal pumping. The pressure curves are again omitted due to their similarity to previously discussed data. Figure #13 shows the flow rate curves obtained for this test. The bulb starts to enter the furnace at position 7. At position 10 an increase in the outgassing is evident. The gas temperature at this position is estimated to be 70°C. A greater amount of pre-pumping would be highly desirable in future studies in order to more accurately evaluate the early stages of outgassing. No ill effects on the bulb were noted as a result of this test. The gas ratio was 12.

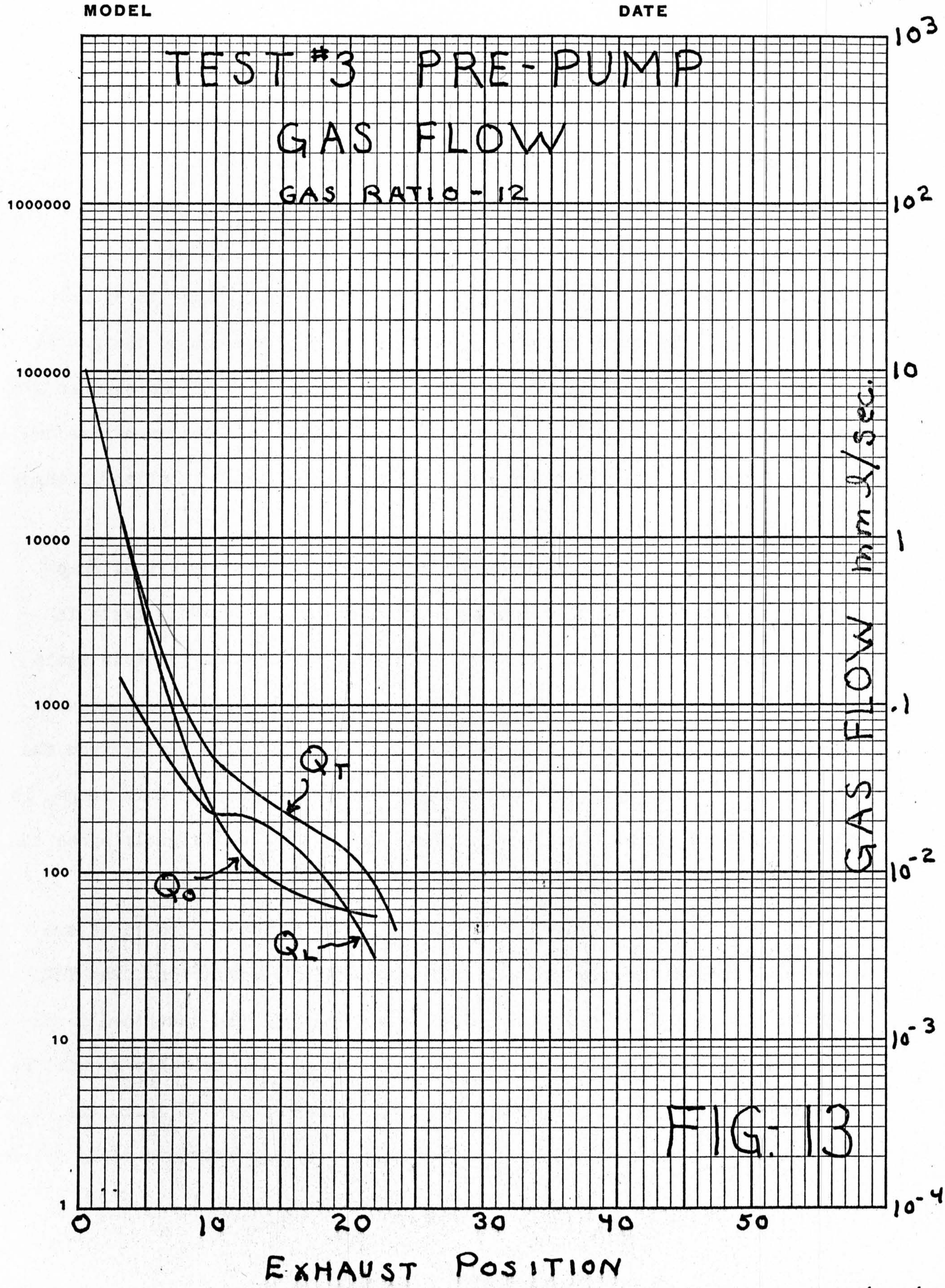


FIG. 13

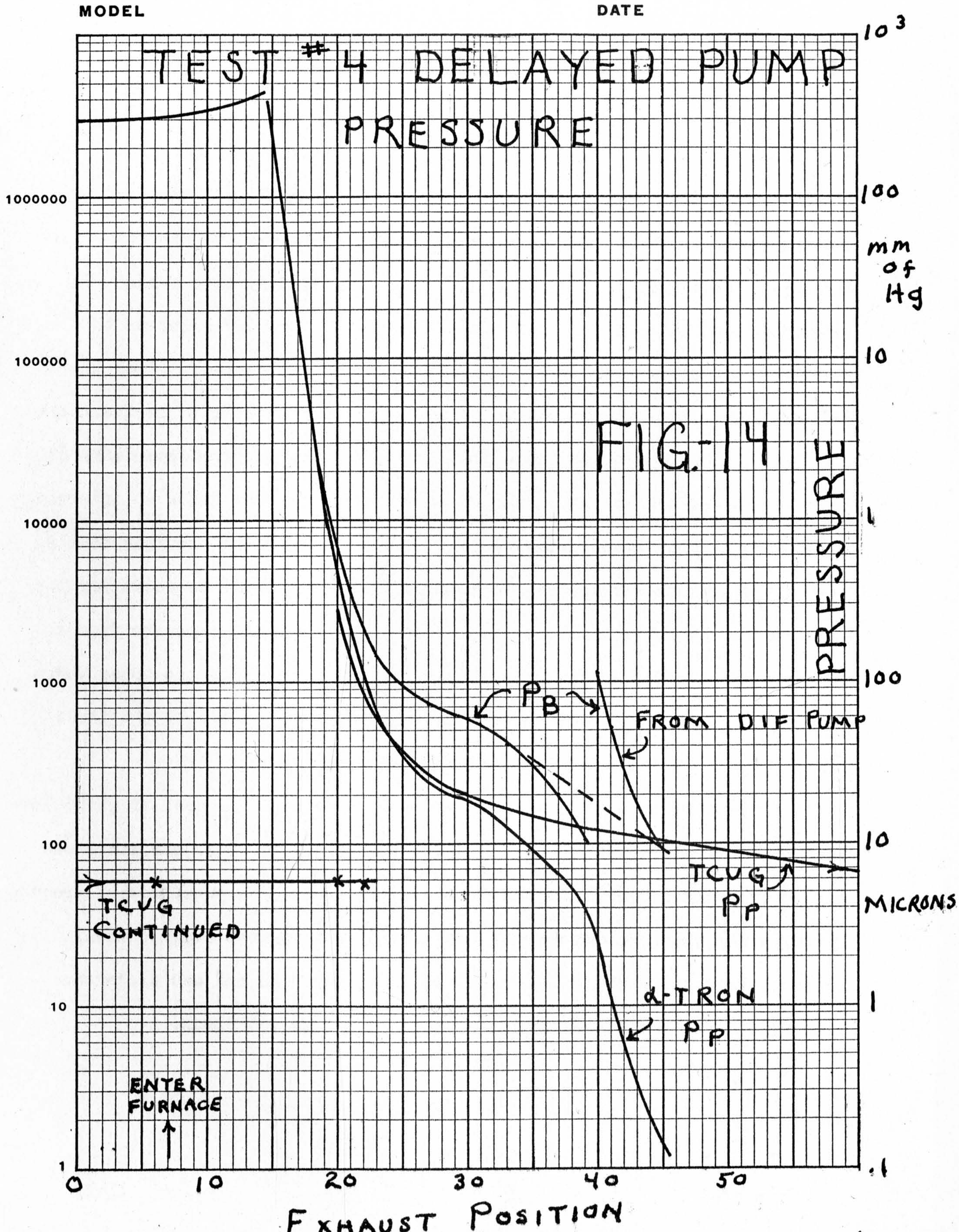
1/16/57
D.J.S.

TEST #4 DELAYED PUMP - PRESSURE

In order to extend the outgassing curve into more advanced positions, a tube was run for which the pumping action was deliberately delayed. A small amount of pre-pumping reduced the bulb pressure to 300 mm to avoid pressure rise above one atmosphere when the furnace heat began to expand the gas. Since the total outgassing is such a small percent of the gas in the tube, the pressure rise observed is a good indication of the average gas temperature within the bulb. Careful measurement of this pressure rise could be used to develop the thermal correction to the graphical solution discussed previously.

The slope of the pressure decay with time after the mechanical pump was turned on is steeper than had been observed in all previous tests in which the slopes had always been the same. The explanation for this again resides in the temperature effect on the gas flow. This is a complex situation in that the alphatron vacuum gage is near the hot gas coming from the tube, but the mechanical pump, which is limiting the speed in this range, is quite a distance removed and the gas must have cooled considerably since the pump speed is not temperature dependent.

The construction of the bulb pressure curve is again composed of two parts--the mechanical pump and the diffusion pump. In this test, the TCVG pressure remained at 6 microns. In previous tests, it had continued to decrease to 3 or 4 microns. This is suggestive of a leak, possibly around the port rubber. The gas ratio of this bulb was in excess of 100 indicating a gassy bulb. On the assumption that the mechanical pump pressure was 3 microns high, we can calculate the expected bulb pressure as being 5×10^{-5} mm of Hg.


MODEL
DATE
TEST #4 DELAYED PUMP
PRESSURE
FIG-14
PRESSURE
10^3
100
mm of Hg
10
1
100
10
MICRONS
1
.1
1000000
100000
10000
1000
100
10
1
P_B
FROM DIF PUMP
TCUG P_P
TCUG CONTINUED
α-TRON P_P
ENTER FURNACE
0
10
20
30
40
50
EXHAUST POSITION

1/16/57
D.J.S.

TEST #4 DELAYED PUMP - GAS FLOW

Figure #15 is a graph of the gas flows for this test. The first interesting observation is the fact that the observed flow is greater than the theoretical. This is a direct result of the temperature situation just discussed. The result of this is that Q_L is negative in this range. The interpretation is that the system speed is faster than indicated on the graphical solution. This is the result which would be expected from the increased gas temperature. When the mechanical pump ceases to be the limiting factor, the tubulation takes over. Here the temperature dependency is less severe and the errors in the Q_L curve decrease. The error in this range would also be consistent with any temperature error in the previous test so that the outgassing curves can be compared. The initial rise shown for the Q_L curve is, therefore, not realistic, but represents its recovery from a negative value. The diffusion pump warming up again limits the upper range of the outgassing curve. From the previous data in this range, the three curves have been estimated and are shown in dotted lines.

From the nature of all the curves, excluding the TCVG one, it would have been expected that this tube would have been good. Yet, the gas ratio was high. In order to establish that the process of delayed pumping will produce a good tube, the test was repeated on a different exhaust buggy without pressure instrumentation. The resulting tube was good and was placed on life test. The results of the life test are not as yet known.

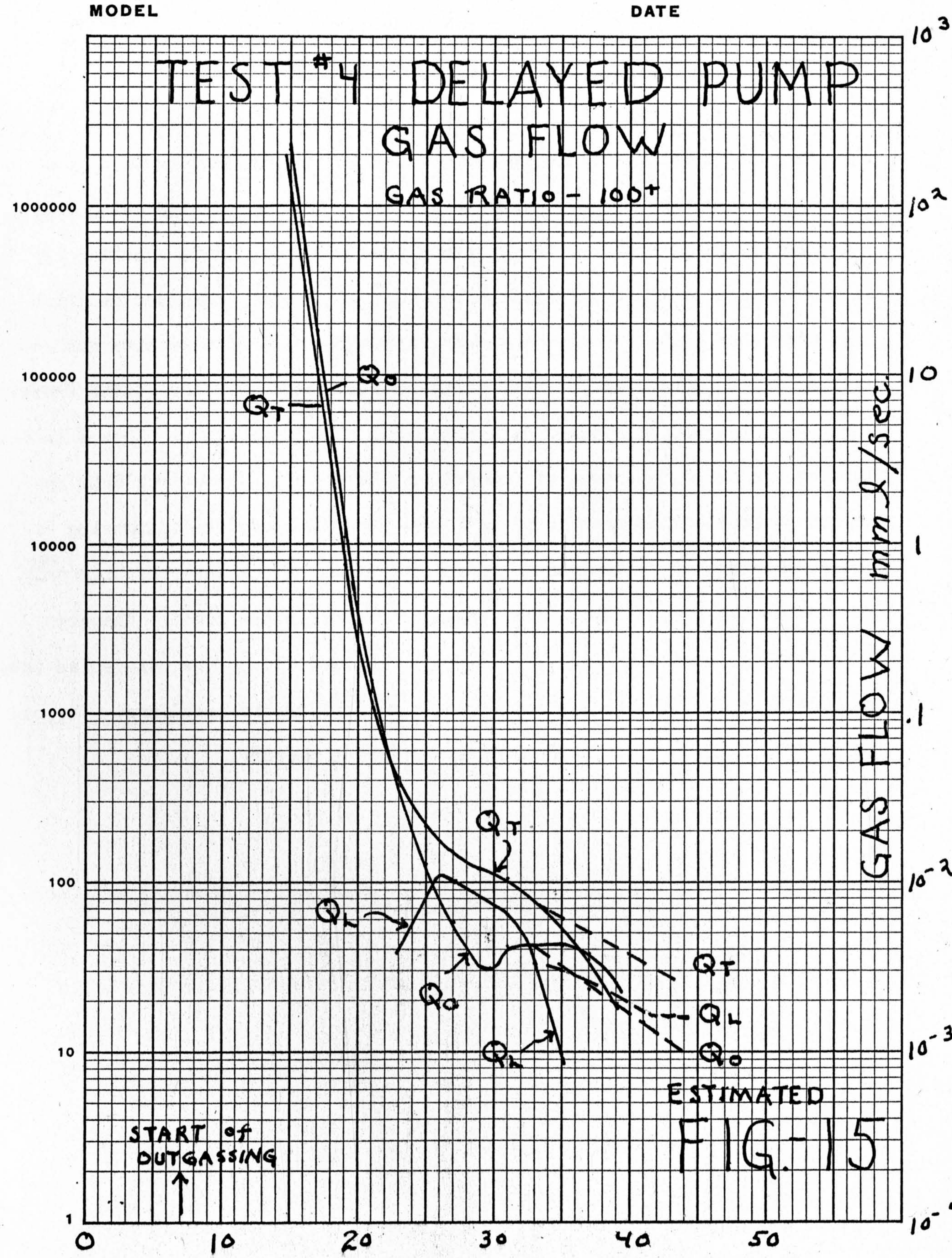


FIG. 15

1/16/57
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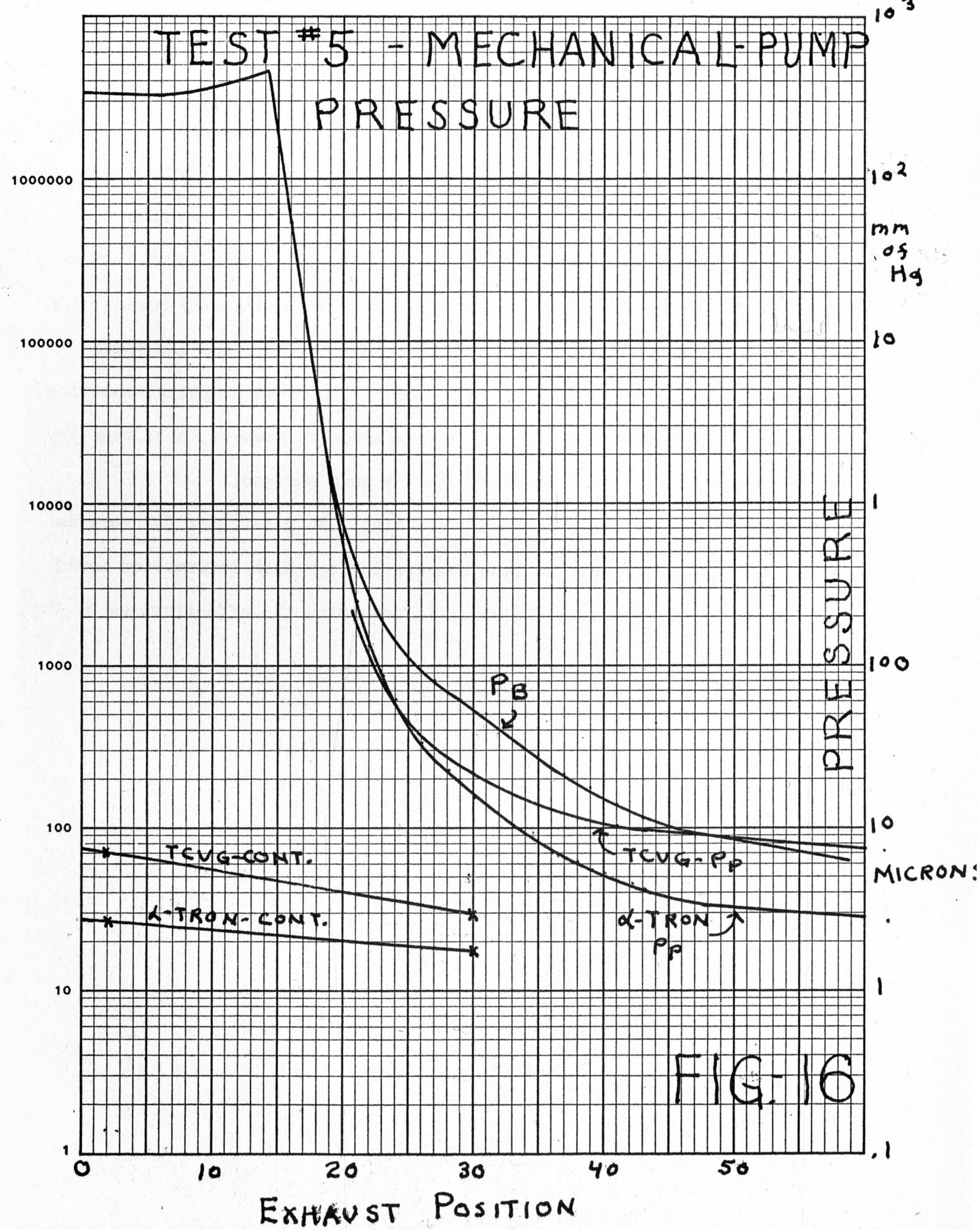
TEST #5 MECHANICAL PUMP - PRESSURE

From observations of the pressure decay in the previous test, it was speculated that the same degree of outgassing could be obtained using only a mechanical pump; however, the pressure in the bulb would be considerably higher because of the high ultimate pressure of a mechanical pump relative to a diffusion pump. If the outgassing is complete, the only extra gas remaining in the tube would be that in the gaseous state. After getter flash, the pressure would be reduced at a rate of 2.3 V/S per decade. Here V is the tube volume and S the speed of the getter. Additional getter would be required to handle this additional gas. In order to study the outgassing characteristics of a tube under these conditions, a test was run using only the mechanical pump. In addition, delayed pumping was applied. The abnormally high pressure reduction is again observed due to the hot gas in the bulb. The bulb pressure was converted from the alphatron readings. The end point TCVG reading at position 90 was a normal 3 microns.

MODEL DATE



1/17/57
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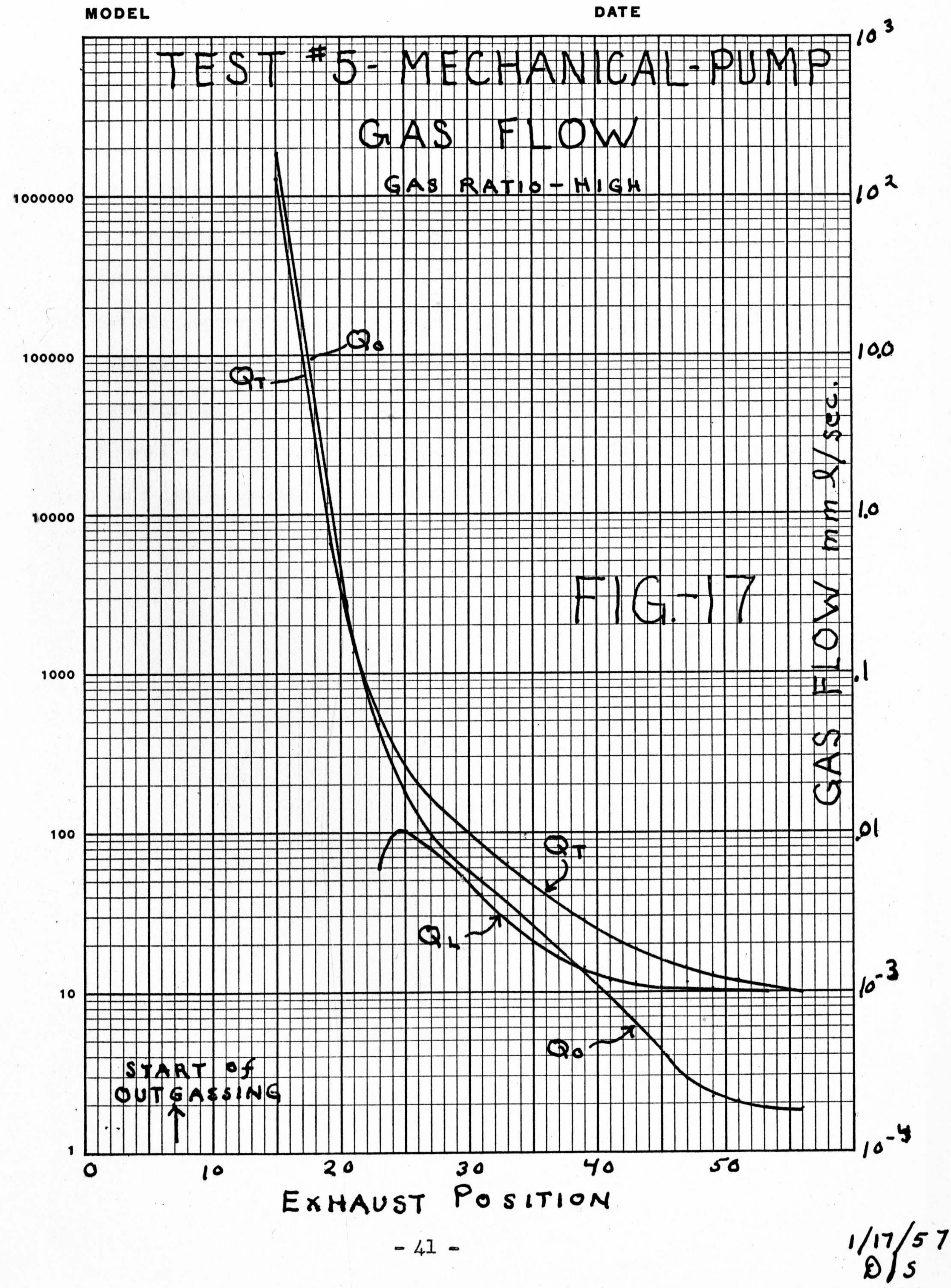
TEST #5 MECHANICAL PUMP - GAS FLOW

The resulting flow curves for this test are given on Figure #17. Q_O is again greater than Q_T as previously discussed. The outgassing curve starts out quite similar to the previous curves, but has a tendency to flatten as the base pressure of the mechanical pump is approached. In this range, it is difficult to know how much of the mechanical pump pressure is due to gas flow and how much is due to the pump, either from oil vapor pressure or water vapor contamination. In the original graphical solution, two microns was assumed as the pump base pressure. However, this can vary between cycles as the moisture level in the pump changes.

The gas ratio of this bulb was very high. No gas ratios for various periods of time after getter flash are available. Such information would be desirable in future tests in order to determine the effectiveness of the getter.


MODEL
DATE
TEST #5- MECHANICAL-PUMP
GAS FLOW
GAS RATIO - HIGH
1000000
100000
10000
1000
100
10
1
10^3
10^2
10.0
1.0
.1
.01
10^{-3}
10^{-4}
GAS FLOW mm l/sec.
FIG.-17
Q_0
Q_T
Q_T
Q_L
Q_0
START of
OUTGASSING
0
10
20
30
40
50
EXHAUST POSITION
1/17/57
D/S

COMPOSITE OUTGASSING CURVE

All the outgassing curves from the previous tests have been combined on Figure #18. Recall that Test #3 was pre-pumped and would have the best accuracy in the early stages. Test #4 was the delayed pumping and would have the greatest accuracy at the end. Test #5 was with the mechanical pump. Considering that different tubes, different processes, limited facilities and gages, and a short period of planning and test time are all involved, the results are in remarkably good agreement. An improvement in instrumentation would make it possible to extend the range to lower outgassing levels so that the entire process can be studied rather than only the start of the process.

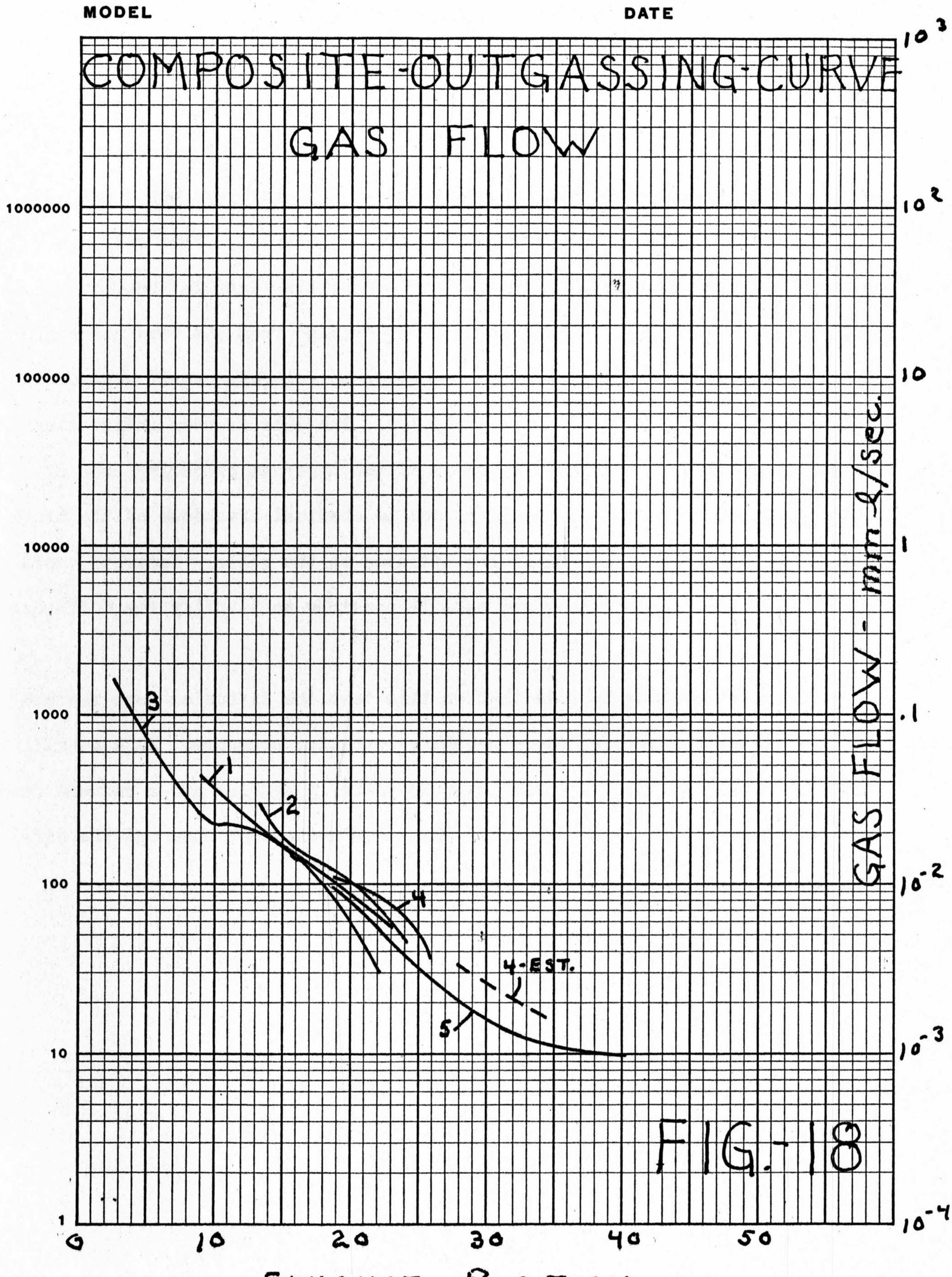


FIG.-18

1/17/57
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TEST #6 NO BAKE-OUT - PRESSURE

In order to establish the sensitivity of the method in observing a change in outgassing conditions, a cathode-ray tube bulb was taken off the line before bake-out and brought directly to exhaust. This bulb was given a pre-pump type of exhaust test. The resulting data is shown on Figure #19. The change in outgassing is so evident from the pressure curve that the ability of vacuum process evaluation to determine small changes in outgassing has obviously not been evaluated. The data is very interesting in that it points out the effectiveness of the bake-out preceding exhaust. The pressure pulses observed could be due to chemical breakdown of the black paint, the lacquer, or any remaining hydrates on the glass. Separate tests on the different components would make it possible to identify the different pressure peaks.

It is interesting to note that on this test the diffusion pump reached its operating temperature before reaching operating pressure. As a result, the speed curve on the graphical analysis properly applies and a reduced dead band is observed at the transition between the mechanical pump and the diffusion pump.

MODEL DATE

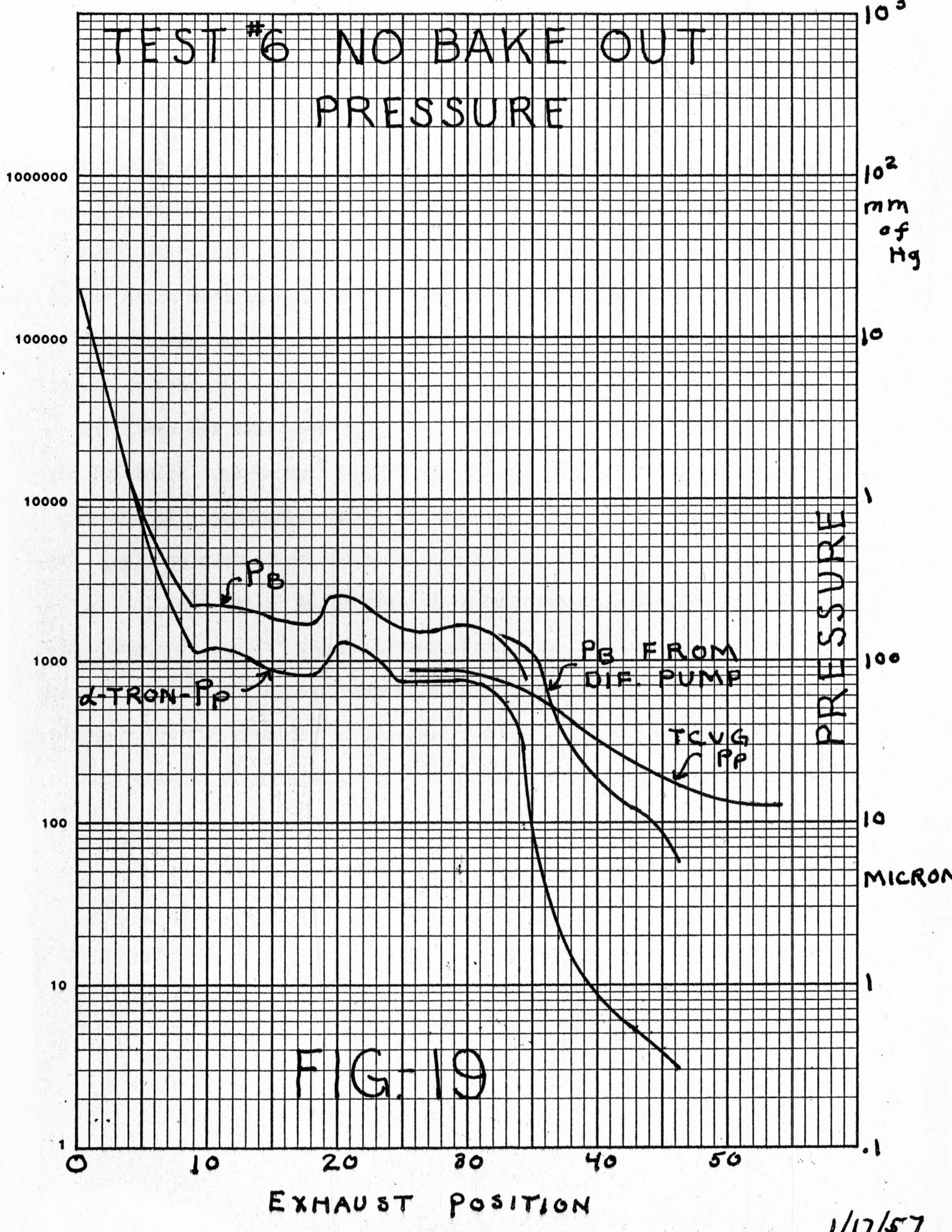

FIG. 19

1/17/57
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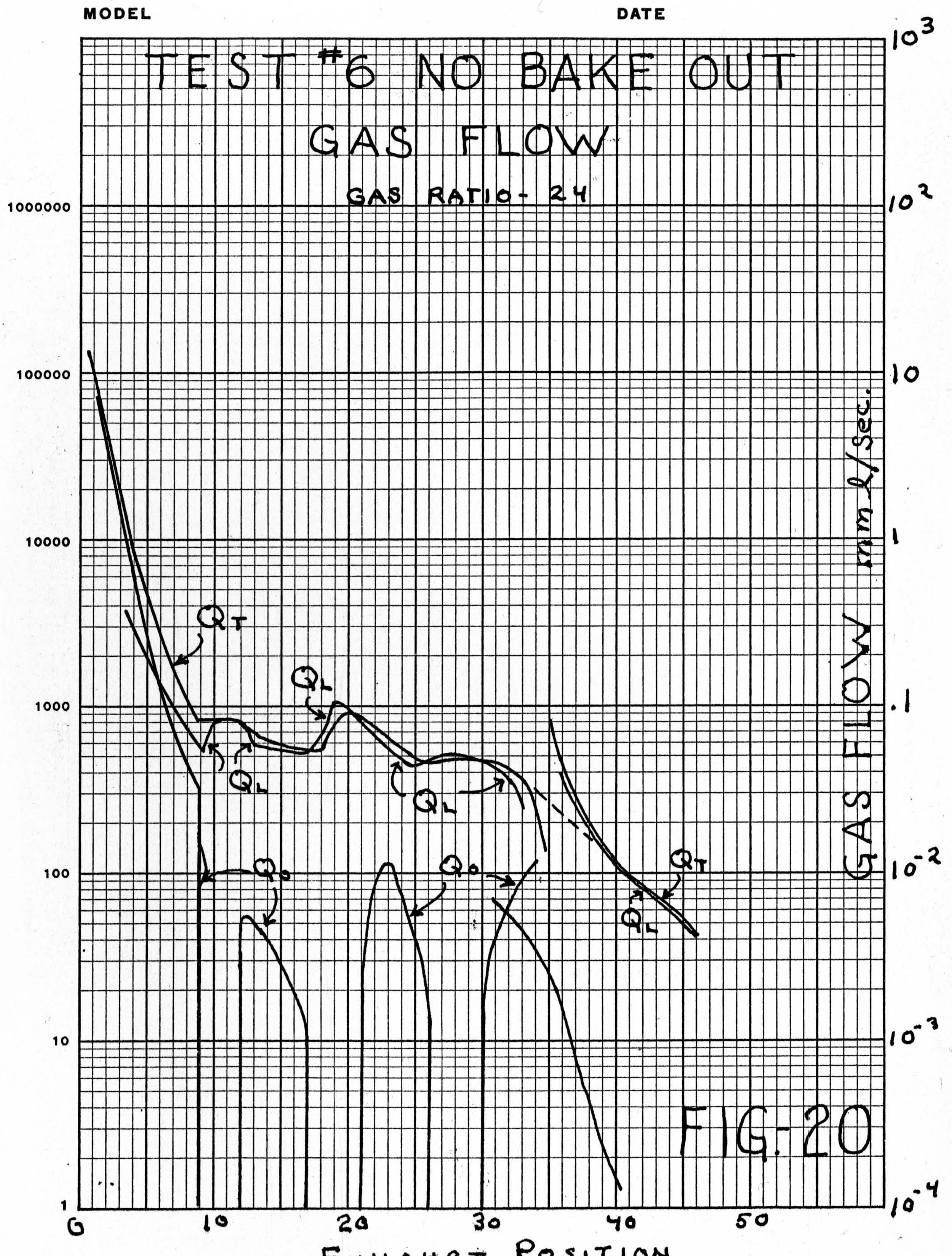
TEST #6 NO BAKE-OUT - GAS FLOW

The resulting flow rate curves for the test are given on Figure #20. The curve appears complex because of the tendency of Q_O, the flow rate <u>out</u> of the bulb to oscillate between plus and minus values. Whenever Q_O becomes negative, the outgassing, Q_L, exceeds the theoretical flow. At about position 32, the outgassing has apparently passed its maximum value and as the pressure decreases the diffusion pump takes hold. If we assumed that the outgassing curve continued at its present slope, as is characteristic of many outgassing processes at constant temperature, then the resulting pressure at position 90 would still be 7×10^{-5} mm of Hg. Actually, additional gas is added by the R.F. and filament activation. Offsetting this would be the decrease in outgassing as the bulb began cooling. Comparing the estimated pressure with that predicted in the test in which a leaker was indicated and also their resulting gas ratios, it appears that the reduction in outgassing rate with temperature is greater than the increase caused by R.F. and filament activation. This is not too surprising when the extreme temperature dependency of outgassing is considered.


MODEL
DATE
TEST #6 NO BAKE OUT
GAS FLOW
GAS RATIO - 24
1000000
100000
10000
1000
100
10
1
10^3
10^2
10
1
.1
10^{-2}
10^{-3}
10^{-4}
GAS FLOW mm l/sec.
Q_T
Q_L
Q_0
G
10
20
30
40
50
EXHAUST POSITION
FIG-20

1/17/57
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TITLE

Preliminary Vacuum Outgassing Study for Cathode-Ray Tubes

ABSTRACT

Preliminary outgassing studies were made on seven cathode-ray tube bulbs utilizing the techniques of "vacuum process evaluation". The purpose of the test was to establish the feasibility of the technique as an aid in evaluating the effect of various materials, processes and equipment on the exhaust cycle.

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CONCLUSIONS

The tests showed good correlation within the limits over which data could be taken. Several problems arose which must be solved for future tests. With improved instrumentation, the technique should be a valuable tool for investigating various exhaust processes.

INFORMATION PREPARED FOR Cathode Ray Tube Department

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AUTHOR D. J. Santeler D. J. Santeler June 26, 1957

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