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HELIUM LEAK TESTING TECHNIQUES: CONTAINMENT OF HELIUM ESCAPING FROM LEAKS BY POLYTHENE SHEETS

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by

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HELIUM LEAK TESTING TECHNIQUES: CONTAINMENT OF HELIUM ESCAPING FROM LEAKS BY POLYTHENE SHEETS

by

J. Milne

A. D. Hammond

ABSTRACT

The basic principles of mass spectrometer helium leak testing of large pressure vessels using polythene sheet as a secondary containment have been investigated and experimental results obtained. Techniques of (a) calibrating helium leaks, (b) measuring the helium diffusion rates through pinholes and (c) measuring permeabilities to helium of polythene are described.

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HELIUM LEAK TESTING TECHNIQUES: CONTAINMENT OF HELIUM ESCAPING FROM LEAKS BY POLYTHENE SHEETS

by

J. Milne and A. D. Hammond

1. INTRODUCTION

In many cases of helium leak detection it is not always practicable to test large surface areas of pressurised vessels for possible leakage by direct use of the sampling probe (also called "snifter"). The method is time consuming and fatiguing for the operator. An alternative to this method is to contain the helium escaping from any suspected areas and measure the build-up of the helium concentrations after a period of time, e.g. 24 hours. This can be most easily and cheaply done with plastic sheet and sealing tape. If the material acting as a secondary containment is impermeable to helium an estimate can be made of the minimum leakage rate that can be detected, after a given time, by a helium mass spectrometer leak detector knowing the free space volume of the containment. However, since polymer films and in particular polythene are permeable to helium it follows that as the helium concentration from a leak builds up, so also must a certain proportion permeate through the polythene. In addition to this loss of helium through the polythene containment, there are other possible areas through which helium may be lost, e.g., pinholes, small air gaps between the metal and sealing tape, tears and possibly adsorption. Each of these factors in addition to those of permeability, free space volume, surface area of polythene will be contributory, to a lesser or greater extent, in determining the minimum size of leak which can be detected during a particular build-up time.

It is of some interest to investigate the various parameters concerned and to establish the reliability of the method and its limitation.

2. GENERAL THEORY

The schematic diagram in Fig. 1 represents the simple case of a small helium leak L_1 atmospheric cm^3/s passing into the free space volume V_x cm^3 contained by the polythene sheet of area A cm^2. The permeability of the polythene to helium is denoted by L_2 atmospheric $cm^3/s/cm^2$ for a partial pressure difference of helium of 1 atmosphere, across the film, balanced by 1 atmosphere of air on the opposite side at room temperatures. It is assumed that the passage of helium through the polymer obeys Fick's first law of diffusion and Henry's law of solution. From these two relations it can be shown that the quantity of helium diffusing through the film is proportional to the difference in partial pressure P_1 and P_2 across the film, and inversely proportional to the thickness 1 cm,

$$\text{i.e.,}\ Q = \frac{K\,A\,(P_1 - P_2)}{l}$$

where K is defined as the permeability constant. K is quoted usually in $cm^3/s/mm$ thickness$/cm^2$ area/cm Hg pressure difference.

For the purposes of this report the permeability will be denoted by L_2, in atmospheric $cm^3/s/cm^2$, per atmospheric partial pressure difference of helium for a thickness of polythene of 0.025 cm. The throughput of helium at any other helium partial pressure P_x atmospheres is thus $L_2 \frac{P_x}{P_o}$ atmospheric $cm^3/s/cm^2$ where P_o is 1 atmosphere pressure.

It is assumed that the helium from the leak L_1 diffuses rapidly and uniformly throughout the volume trapped by the polythene. After a build-up time of t seconds the helium leak raises the helium partial pressure in V_x by P_x atmospheres. Thus under dynamic flow conditions:

$$\text{Inleakage of helium } (L_1) - \text{outleakage} = V_x \frac{dP_x}{dt}$$

The outleakage term includes not only the loss by permeation through the polythene but also that through pinholes and gaps between the sealing tape and the metal surface. If L_3 atmospheric cm^3/s is the overall loss of helium through air gaps, etc., for the system described when the helium partial pressure difference is 1 atmosphere and it is accepted that the loss of helium through such gaps is one of simple gaseous diffusion, then it can be shown that:

$$L_1 - \frac{P_x}{P_o}\left(L_2A + L_3\right) = V_x \frac{dP_x}{dt} \qquad (1)$$

Rearranging terms in equation (1) and integrating between t = 0 for $P_x = 0$ and t = t for $P_x = P_x$ we have for the partial pressure of helium beneath the polythene after time t

$$P_x = \frac{L_1 \; P_o}{AL_2\left(1 + \frac{L_3}{AL_2}\right)}\left\{1 - e^{-\frac{L_2A + L_3}{V_x \; P_o} \cdot t}\right\} \qquad (2)$$

Since, however, concentrations of helium in atmospheric air are measured, the equation can be written in the form:

$$C_t = C_{max}\,(1 - e^{-kt}) \qquad (3)$$

where $C_{max} = \frac{L_1}{AL_2\left(1 + \frac{L_3}{AL_2}\right)}$ and $k = \frac{L_2A + L_3}{V_x \; P_o}$

If $(L_2A + L_3) \longrightarrow 0$ the term $e^{-kt} \longrightarrow 1 - kt$ for $kt \ll 1$

thus from equation (2)

$$P_x = \frac{L_1 \; P_o}{AL_2 + L_3} \cdot \left(\frac{L_2A + L_3}{V_x \; P_o} \right) \cdot t \qquad (4)$$

i.e. $P_x = \frac{L_1 t}{V_x}$

which is the simple case of a leak leaking into an impermeable vessel of volume V_x or in other symbols (see equation 1).

$$L_1 = V_x \frac{dP_x}{dt} \qquad (5)$$

3. EXPERIMENTAL PROCEDURES

3.1 Polythene Containment Technique

A sheet of polythene 0.025 cm thick with an effective area of 3350 cm^2 and dimensions shown in Fig. 2 was placed over a clean stainless steel surface and sealed down at the edges with masking tape. The polythene was held as close as possible to the stainless steel surface to reduce the free space volume between the polythene and stainless steel sheet. To permit measurement of the helium concentration in the volume trapped by the polythene and stainless steel sheet, sampling points were located at the positions shown in Fig. 2. The leak L_1 was inserted through the hole in the top left-hand corner of the stainless steel sheet. A modification of an Edwards vacuum union fitted to the plate made a leak tight seal around the glass support of the helium leak and prevented any significant back diffusion of helium from the containment to the atmosphere. At frequent intervals the build-up of the helium concentration due to L_1 was measured at the different sampling points. To carry out a measurement one of the small plugs was removed and the sampling probe inserted in as short a time as possible. Particular care was taken to minimise the chances of helium escaping from these plugs. The build-up time normally lasted the recommended 24 hours laid down by the leak testing specification for the Dragon Reactor Experiment or until the helium concentration had built-up to its maximum value.

For assessing the value of the technique, the free space volume must be measured. This was done by two methods. In the first one, the air trapped between the polythene and metal surface was pumped out by a rotary pump into an inverted water-filled measuring cylinder. This method was somewhat unsatisfactory because of the air leakage due to air gaps, possibly pinholes, etc., and permeation of air. However, it did offer a useful guide to the degree of leak tightness that might be achieved in such a system. The alternative method, open to similar disadvantages, forced the trapped air out of the space by compression into a measuring cylinder. This method would give an underestimate of the volume, and the former an overestimate. The two values, came to 460 cm^3 for the compression technique and about 600 cm3 for the vacuum method. An air film of 0.1 cm thick would have had a volume of 335 cm^3.

The C.E.C. helium mass spectrometer leak detector type 24-120 measured the concentration of the helium in air trapped between the polythene and metal surface. It has been shown [1] that the helium mass spectrometer produces a signal which is proportional to the partial pressure of helium in a gas mixture, or to the helium concentration in the gas mixture. For an air pressure of 0.13 microns of Hg at the mass spectrometer detecting head the helium content in the air gave a signal of about 40 divisions on the most sensitive scale.

3.2 Calibration of Helium Leaks

It has been normal practice to calibrate helium leaks by attaching them to a vacuum system and a helium mass spectrometer leak detector, which has been calibrated against a known standard leak in cm^3/s/division. The method however does not simulate the conditions under which helium might be expected to escape from a leak into the normal atmosphere. This is particularly the case for a viscous flow type of leak. As a result a method has been devised to calibrate both helium viscous flow and diffusion type leaks against the normal concentration of the atmosphere. The figure for the helium concentration in air was determined by E. Glueckauf in a paper published in the Royal Society Proceedings [2]. According to this paper the average helium content of air was 5.239×10^{-6} cc per cm^3 of air, to an accuracy of $\pm 0.002 \times 10^{-6}$ cm^3. The standard error of an individual measurement was 0.008×10^{-6} cm^3.

In principle the unknown leak is fitted to a leak tight volume of known capacity. The increase in the helium to air concentration is measured over suitable time intervals by sampling the air with a helium mass spectrometer leak detector probe. The method permits large or small leaks in the range 1×10^{-2} to 10^{-8} atmospheric cm^3/s to be measured.

In Fig. 3 are shown the apparatus and the results obtained for a leak of about 10^{-4} cm^3/s; inset is a sketch of the glass leak and its mounting. Fig. 4 shows the apparatus which was used to calibrate the fused silica type of leak. The calibration results of two helium standard leaks are given in Figs. 5 and 6.

3.3 Loss of Helium through Pinholes

Evidence from earlier experiments on the build-up of helium concentration beneath polythene films showed that helium was being lost as rapidly through air gaps as through the polythene, e.g., ineffective sealing of the fused silica leaks can account for a very large portion of the helium losses since, at this point, the helium concentrations are so much higher than elsewhere beneath the polythene. To a lesser extent the losses in the gap between the adhesive tape joining the polythene to the metal surface can account for a further portion of the helium losses if only because of its long peripheral length. Such small gaps and pinholes are very difficult to locate visually. In one instance a slight excess pressure of nitrogen (1 in. water gauge) was added to the volume containing the polythene, etc., and the seal between the polythene and metal surface soap tested for leaks; innumerable leaks were located by this method.

To obtain some idea of the geometrical size of leaks which could account for some of the helium losses beneath the polythene, experiments were made to measure the loss of helium through pinholes. Each pinhole was fitted in turn to a volume containing a suitable helium in air concentration (see Fig. 7). The helium diffusing through the pinhole was collected in a known volume of air and the helium concentration measured over suitable intervals of time. The results for one pinhole have been plotted in Fig. 8 which shows that the logarithm of the helium concentration term $\frac{C_o - C_t}{C_o}$ falls off linearly with time. This shows that the rate of rise of the helium concentration is proportional to the concentration gradient across the pinhole. On the basis of this information an estimate can be made of the 'real' leak size L_o in atmospheric cm^3/s, i.e., the quantity of helium being lost through the hole by diffusion with one atmosphere of helium across the pinhole balanced by an equal pressure of air on the opposite side.

In Fig. 9 are plotted the leak sizes of pinholes of different radius each with the same length. Two separate measurements were made with each pinhole. According to the general theory of diffusion of gases through pinholes one should expect by plotting the logarithm of the leak size against the logarithm of the radius a slope of 2 for the length $l \gg$ the radius r. As the experiment has shown this slope is less than 2 and nearer to 1. The length to diameter ratios for the points on this curve ranged from 1.25 down to 0.03. To confirm the above premise capillaries of similar diameter to the above pinholes but of length 1.0 cm, were measured in the same apparatus. The leak rate - radius curve produced by these points gave a curve of slope 2 with length to diameter ratios ranging from 100 down to 2.5. Only further work can show whether or not as a general rule the leak size of a hole with length/diameter ratio less than 1 is proportional to the radius and when greater than 1 is proportional to the square of the radius. The evidence is however sufficient to show that leakage through gaps and holes can have a significant and adverse effect on the performance of polythene sheets as secondary containments.

A pinhole having a leak of about 1×10^{-3} cm^3/s will hardly effect the build-up of helium beneath the polythene area described above unless it is very close to a region of high helium concentration, e.g., near to the helium leak. For pinholes with much larger leak rates the loss of helium from beneath the polythene becomes much more serious.

3.4 Permeability of Polythene to Helium

Following the measurements described in Section 3.1 five small samples of polythene were cut from the large sheet and mounted between two washers as shown in Fig. 10. Helium pressure was applied to one side and a vacuum to the other of the polythene. A helium mass spectrometer leak detector measured the quantity of helium permeating through the polythene at various absolute pressure differences.

The results are plotted in Fig. 11. From the graphs the permeabilities for an absolute pressure difference of 760 mm (1 atmosphere) have been found for each sample and listed in the Table shown.

According to the theory of gaseous diffusion the flow is directly proportional to the pressure difference. In such cases the curves plotted in Fig. 11 would be expected to have a slope of unity. The slopes are in fact slightly larger. At the helium partial pressures that might be expected across polythene during detection of small leaks as described in 3.1, i.e., between 5 and 40 microns Hg, a slope of one would reduce the permeabilities as measured above by about half. For the order of accuracy that can be expected in such experiments this change of slope from unity is of no immediate interest to this general study.

However, the fact that 5 samples have consistently given slopes greater than unity suggests that either the calibration technique is in error or that the diffusion of helium through polymers does not strictly obey Fick's first law of diffusion. The former case is the more likely of the two.

For the purposes of calculation we shall assume that the permeability of polythene to helium is 2.5×10^{-6} $cm^3/s/cm^2$, a value which agrees closely with other authors [3] [4].

4. RESULTS

In Figs. 12 and 13 are graphed the results of the build-up of the helium concentration as a function of time. For the 1.3×10^{-4} cc/s leak (Fig. 12) it has been necessary to plot the logarithms of the helium concentration against those of the build-up time. Each curve represents the increase in helium concentration at a specific sampling point. The graphical symbols can be identified with a particular hole from the Table given in Fig. 2. To avoid confusion only the concentrations at the sampling points 1, 4, 7 and 9 have been plotted. It is worth noting that the concentrations at points 2 and 3 were slightly higher than at 1 and similarly points 5 and 6 higher than 4. In this case and of course in the general fall of concentration along points 1, 4, 7 and 9 the effects of helium diffusion through the polythene and air are clearly observed. In the 2.7×10^{-8} cc/s leak experiment (Fig. 13) no significant increase of helium concentration was observed at points 4 and 7, i.e., at a distance greater than 40 cm away. Over the range of leaks studied, equilibrium conditions were obtained for the system described in about 17 hours.

5. DISCUSSION OF RESULTS

The curves clearly show that helium is being lost through the polythene and possibly other defects such as pinholes and gaps. If this were not the case the build-up of the helium concentration would follow an increase proportional to time. (This has been confirmed in practice by welding together two stainless steel sheets.) Assuming that the major portion of this loss is by permeation through the polythene, an estimate can be made, from the curves, of the value L_2, by neglecting L_3, the helium leakage losses through air gaps, etc.

Taking a mean curve through each group of points in Figs. 12 and 13 and plotting the logarithm of $\frac{C_{max} - C_t}{C_{max}}$ against time t, a straight line graph is obtained. From the slope of the line, the halving time value of log $\frac{C_{max} - C_t}{C_{max}}$ can be measured, and since it can be shown that the halving time:

$$t_{\frac{1}{2}} = \frac{0.693\, V_x\, P_o}{L_2}$$

it follows that an approximate estimate can be made of L_2 knowing V_x and $t_{\frac{1}{2}}$.

To a near approximation $V_x = 500$ cc. For the helium leak 1.3×10^{-4} cm^3/s the halving time for the above curve is 250 minutes. Thus $L_2 = 2.3 \times 10^{-2}$ cm^3/s or for the area of 3350 cm^2, the permeability at normal room temperatures and pressures is:

$$6.9 \times 10^{-6} \text{ atmospheric cm}^3/\text{s/cm}^2.$$

A similar graph for the 6.6×10^{-7} cm^3/sec leak gives $L_2 = 4.3 \times 10^{-2}$ cc/s and permeability of $1.3 \times 10{-5}$ atmospheric cm^3/s/cm^2.

The theory also shows to a near approximation that as the helium concentration builds-up with time it reaches an asymptotic value defined by:

$$C_{max} = \frac{L_1}{L_2}.$$

Thus for $L_1 = 1.3 \times 10^{-4}$ cm^3/s

and $C_{max} = 2000 \times 10^{-6}$ parts of helium in air

$L_2 = 6.5 \times 10^{-2}$ cm^3/s

and permeability $= 1.9 \times 10^{-5}$ cm^3/s/cm^2.

Similarly for $L_1 = 6.6 \times 10^{-7}$ cm^3/s

and $C_{max} = 15 \times 10^{-6}$ parts of helium in air

$L_2 = 4.4 \times 10^{-2}$ cm^3/s

and permeability $= 1.3 \times 10^{-5}$ cm^3/s/cm^2.

Experimental measurements of the permeability of polythene to helium [3][4] give values a factor of 10 less than those calculated above. The latter values are of course higher than one should expect due to the non-uniform distribution of helium beneath the polythene. It may also be possible that significant amounts of helium escaping through small gaps would give permeabilities larger than the real value for polythene.

If we accept that the permeability of polythene L_2 to helium is 2.5×10^{-6} cm^3/s/cm^2 (see Section 3.4), we can obtain an approximate estimate of L_3 from the relation

$$C_{max} = \frac{L_1}{AL_2\left(1 + \frac{L_3}{AL_2}\right)}$$

The results are quoted in Table 1.

Table 1

Helium Leak L_1 cm^3/s	For $L_2 = 0$, $V_x = 500$ cm^3 He C'_{max} ppm's Calculated	C_{max} ppm's Measured	L_3 cm^3/s
1.3×10^{-4}	2.25×10^4	2×10^3	5.6×10^{-2}
6.6×10^{-7}	1.42×10^2	1.5×10	3.5×10^{-2}
2.7×10^{-8}	8.3	~2	0.51×10^{-2}

For L_2 equal 1×10^{-7} $cm^3/s/cm^2$, most of the helium losses in the above experiments would have occurred through air gaps, pinholes, etc., and would have had a maximum value of 6.5×10^{-2} cm^3/s. In practice (see Section 3.3) such a leak rate could have occurred through a hole 0.2 cm in diameter and 0.012 cm long. For the system used calculations show that for L_2, 2.5×10^{-6} $cm^3/s/cm^2$ and L_3, 4.5×10^{-2} cm^3/s approximately 20% of the helium escaping is being lost through the polythene.

From the experiments carried out the minimum size of leak which could be detected can be calculated approximately from the above relation if one assumes that the minimum detectable change in helium concentration that can be easily measured by a C.E.C. helium leak detector is 1 ppm.

Thus for $C_{max} = 1 \times 10^{-6}$

$A = 3.35 \times 10^3$ cm^2

$L_2 = 2.5 \times 10^{-6}$ $cm^3/s/cm^2$

$L_3 = 4.5 \times 10^{-2}$ cm^3/s

we have $L_{min} = 5.3 \times 10^{-8}$ cm^3/s.

The result agrees favourably with that obtained with the 2.7×10^{-8} cm^3/s helium leak. For areas much larger than the one employed in this investigation it is very doubtful if leaks of this order would be detected. Mathematical solutions [5] for the problem of a point source helium leak losing helium over a very large area of polythene with a gap of 0.1 cm between the polythene and the vessel suggest that a leak 1×10^{-6} cm^3/s could be detected on a radius about 70 cm away. This radius covers an area of 0.38 square metres.

6. CONCLUSIONS

The results give a general picture of the performance of polythene sheet as a secondary containment. For small sealed areas of polythene (0.33 square metres) there is good agreement between the experimental results and the general theory. Leaks as small as 1×10^{-7} cm^3/s can readily be detected under 0.025 cm thick polythene of area 3350 cm^2 after a build-up time of 24 hours. Leaks smaller than this but larger than 6×10^{-9} can also be found by careful sampling over small areas.

By reducing the permeability of the secondary containment, e.g., to 1×10^{-7} $cm^3/s/cm^2$ some slight gain may be obtained in detecting small leaks during the 24 hour build-up time. This gain can be off-set very easily if the free space volume is too large or if the sealing features have small gaps.

For extensive areas of polythene the helium escaping from small leaks is of course diluted very much more rapidly so that one depends on maintaining the polythene as close to the vessel as possible to reduce the rate of diffusion of helium throughout the trapped volume and maintaining as high a concentration of helium in the region of the leak. Theoretical evidence shows that a leak of 1×10^{-6} cm^3/s would be only just detectable at a radius 70 cm away. This radius covers an area of 0.38 square metres. To find smaller leaks one must sample the trapped air beneath the polythene over much smaller areas.

7. ACKNOWLEDGMENTS

The authors wish to thank Mr. F. Wade for his support and encouragement in the work described.

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(Proc. Roy. Soc. A 185, 1945, p.89)

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[5] J. Allen, "Private Communication."

V_x = FREE SPACE VOLUME BETWEEN POLYTHENE AND METAL SURFACE. (CM^3)

P_x = PARTIAL PRESSURE OF HELIUM AT TIME $\underline{t}$ (ATMOSPHERES)

P_0 = ATMOSPHERIC AIR PRESSURE.

A = AREA OF POLYTHENE (CM^2)

L_2 = PERMEABILITY OF POLYTHENE $(CM^3/SEC./CM^2)$

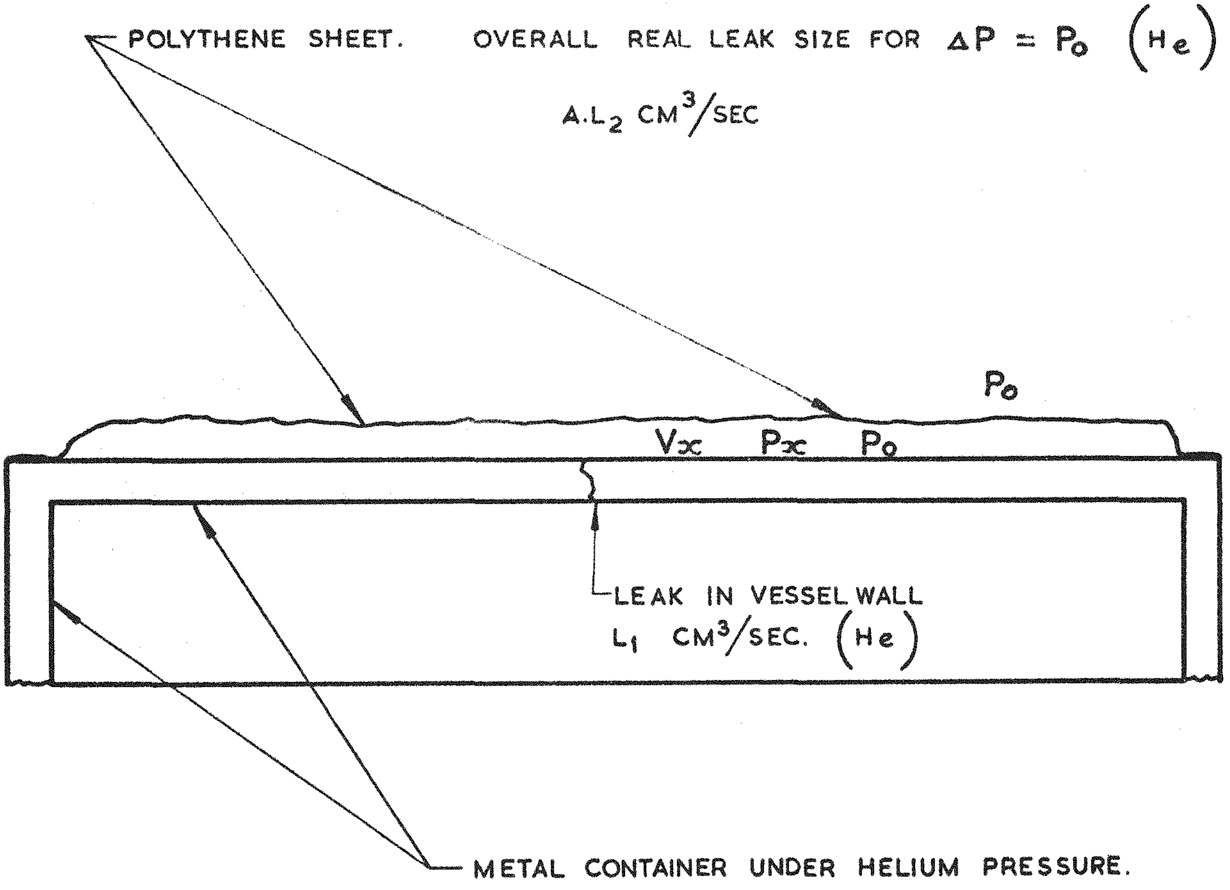
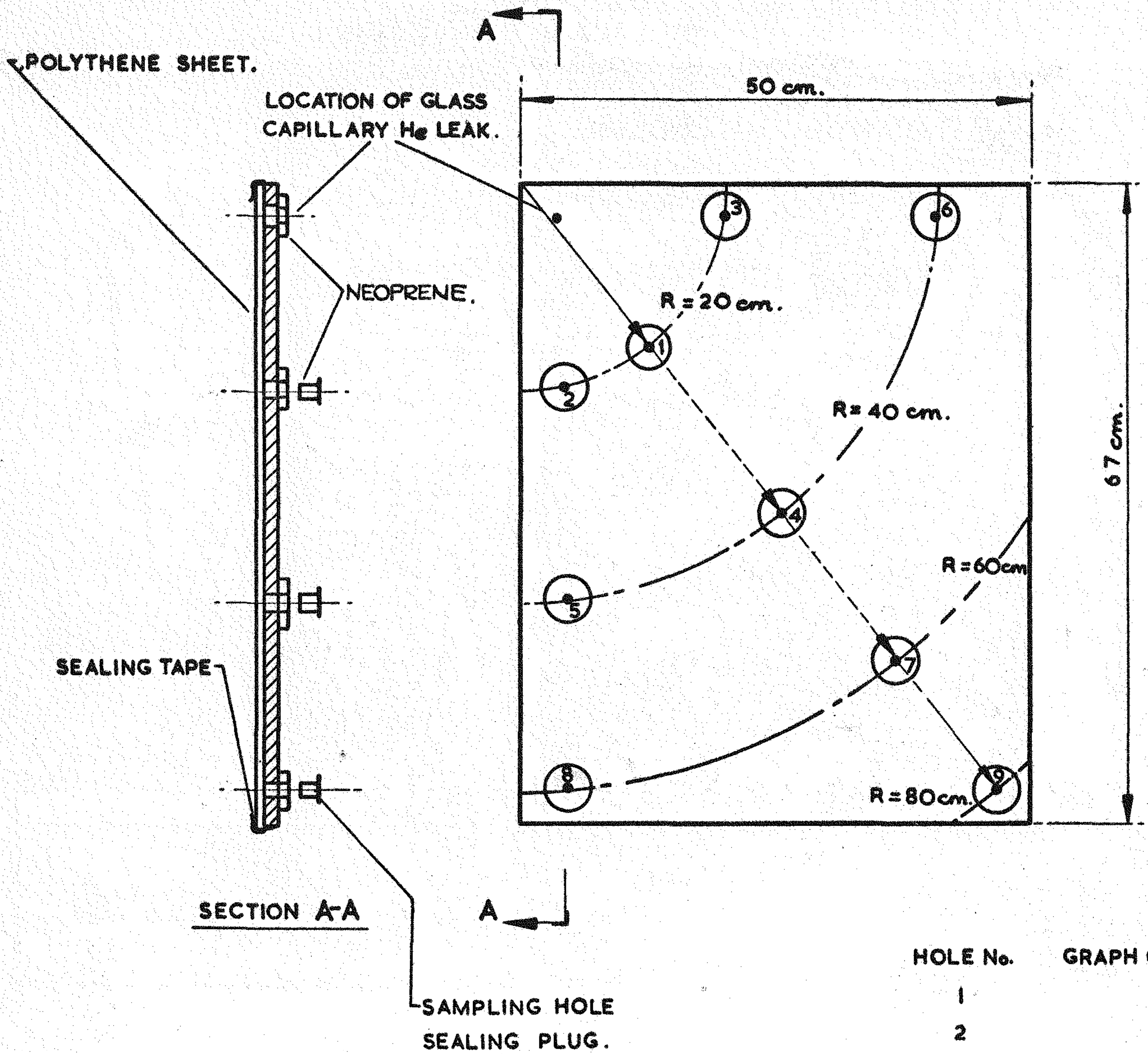
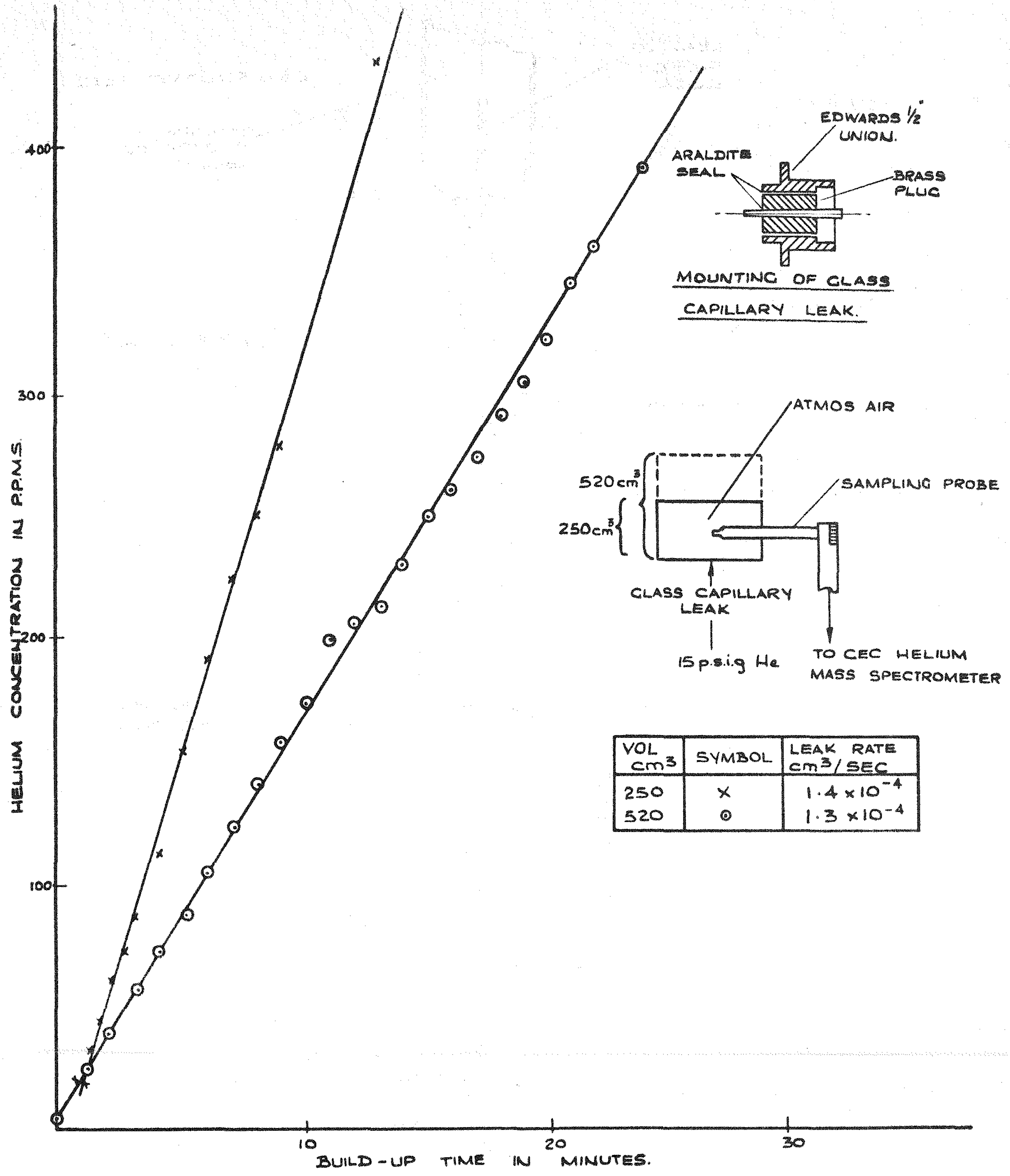


FIG. 1 SCHEMATIC DIAGRAM OF BAGGING TECHNIQUE.



HOLE No.	GRAPH ( ) SYMBOL
1	•
2	X
3	+
4	⊙
5	⊗
6	⊕
7	⊡
8	⊠
9	◈

FIG. 2 LOCATION OF SAMPLING PROBE POINTS TO MEASURE HELIUM CONCENTRATION BUILD-UP BETWEEN POLYTHENE AND STAINLESS STEEL PLATE.



VOL cm^3	SYMBOL	LEAK RATE cm^3/SEC
250	×	$1{\cdot}4 \times 10^{-4}$
520	⊙	$1{\cdot}3 \times 10^{-4}$

FIG. 3. METHOD AND RESULTS OF CALIBRATING A 10^{-4} CM^3/S GLASS CAPILLARY LEAK.

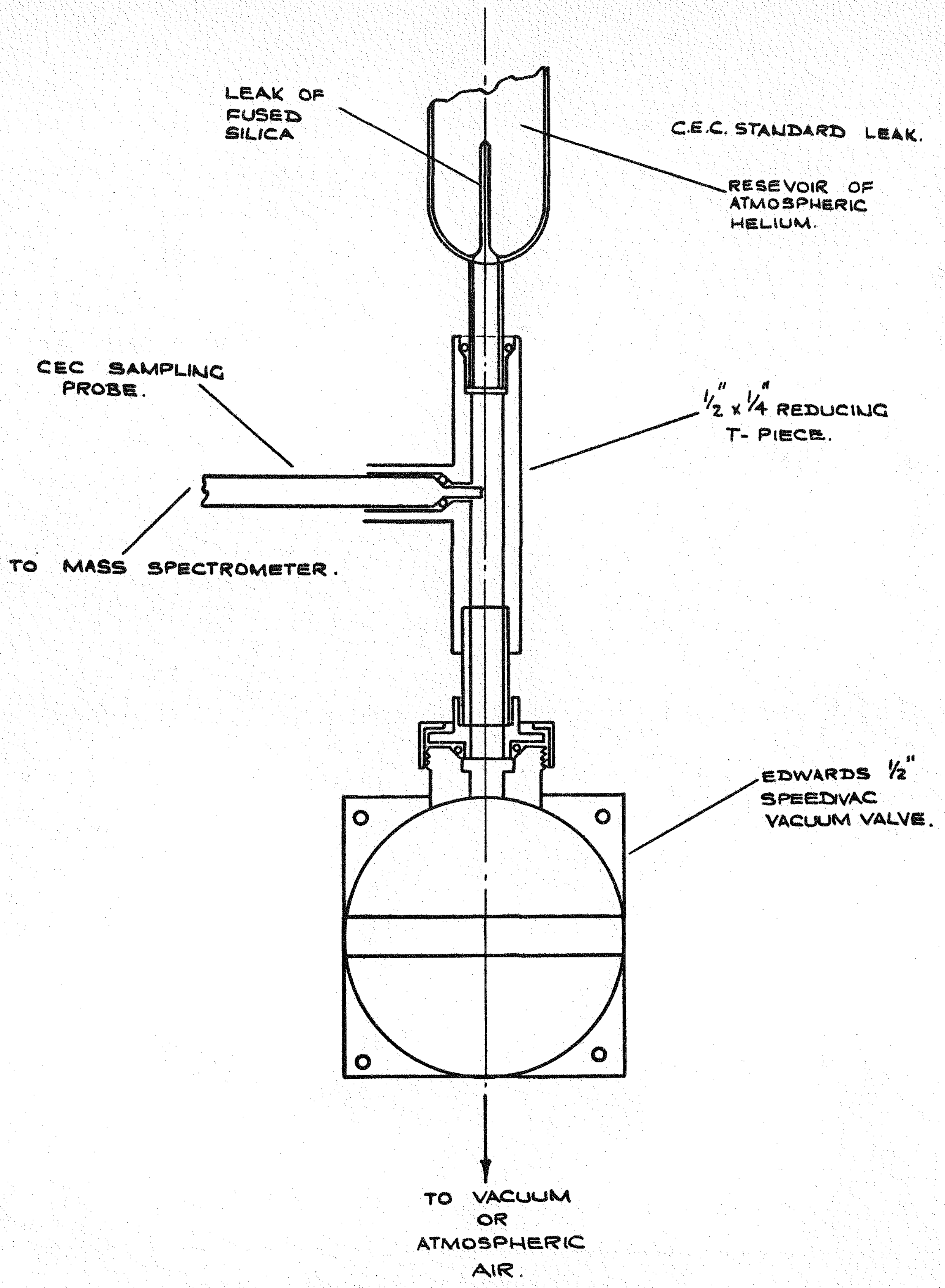
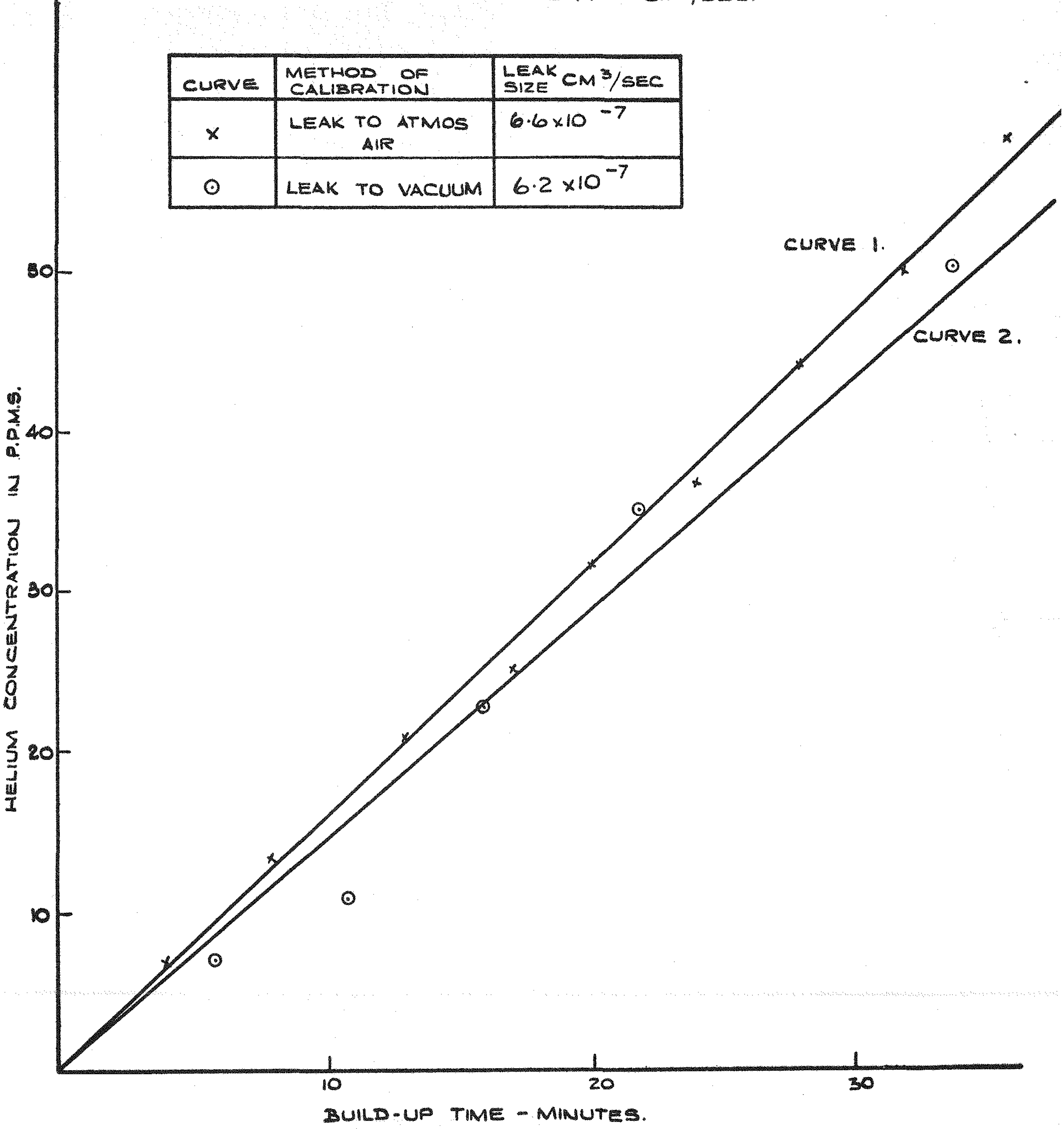


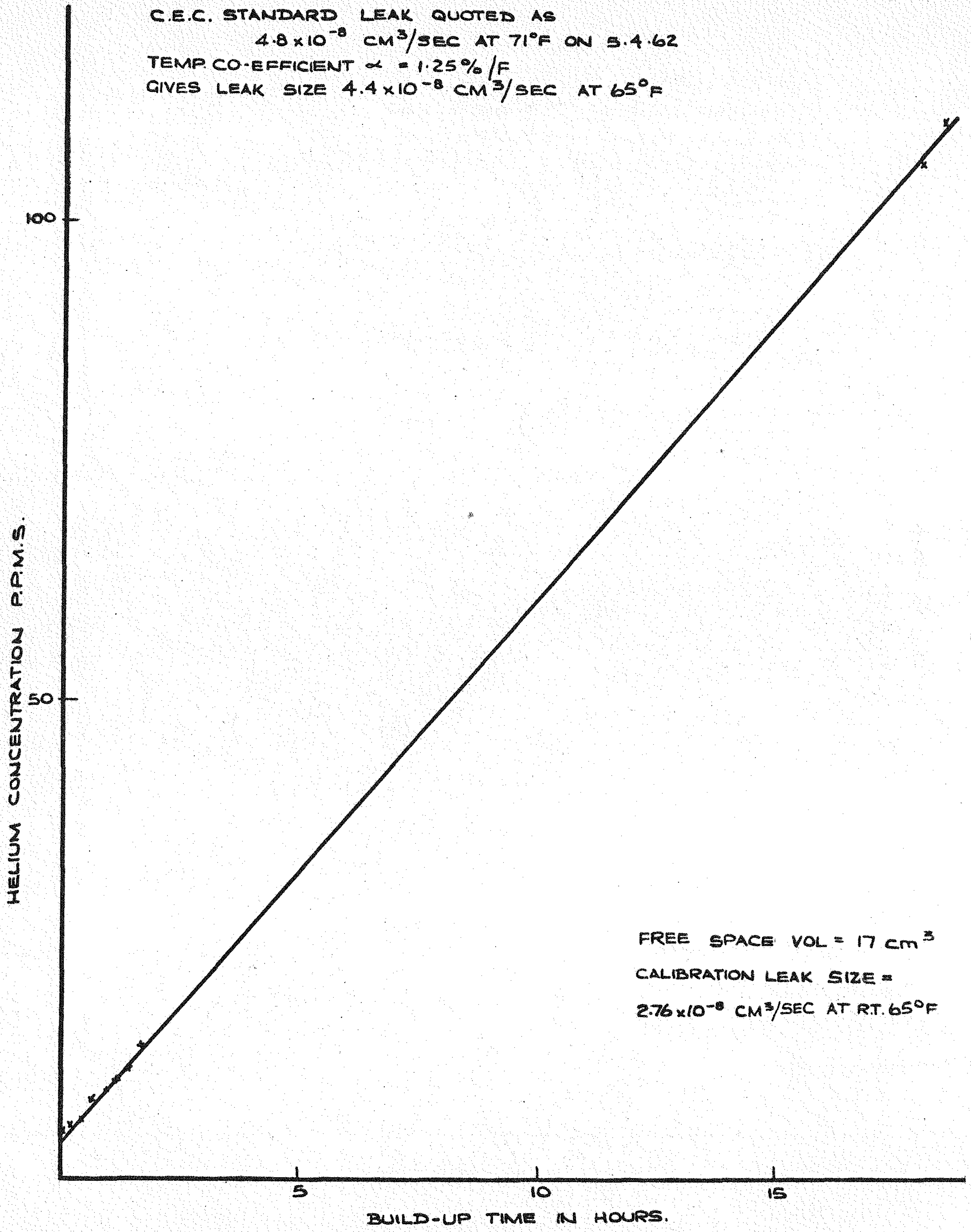
FIG.4. APPARATUS TO CALIBRATE C.E.C. STANDARD HELIUM LEAKS.

CEC STANDARD LEAK QUOTED AS
$8{\cdot}2 \times 10^{-7}$ CM^3/SEC AT 79°F ON 5·11·60
TEMP CO.-EFF. α = 1·5 %/°F
PRESENT LEAK SIZE AT 65°F = $5{\cdot}9 \times 10^{-7}$ CM^3/SEC.



CURVE	METHOD OF CALIBRATION	LEAK SIZE CM^3/SEC
×	LEAK TO ATMOS AIR	$6{\cdot}6 \times 10^{-7}$
⊙	LEAK TO VACUUM	$6{\cdot}2 \times 10^{-7}$

FIG.5. CALIBRATION OF C.E.C. STANDARD HELIUM LEAK AGAINST HELIUM CONCENTRATION IN AIR.



C.E.C. STANDARD LEAK QUOTED AS
4.8×10^{-8} CM^3/SEC AT 71°F ON 5.4.62
TEMP. CO-EFFICIENT $\alpha = 1.25\%$/F
GIVES LEAK SIZE 4.4×10^{-8} CM^3/SEC AT 65°F

FREE SPACE VOL = 17 cm^3
CALIBRATION LEAK SIZE =
2.76×10^{-8} CM^3/SEC AT R.T. 65°F

FIG.6. CALIBRATION OF C.E.C. STANDARD HELIUM LEAK AGAINST HELIUM CONCENTRATION IN AIR.

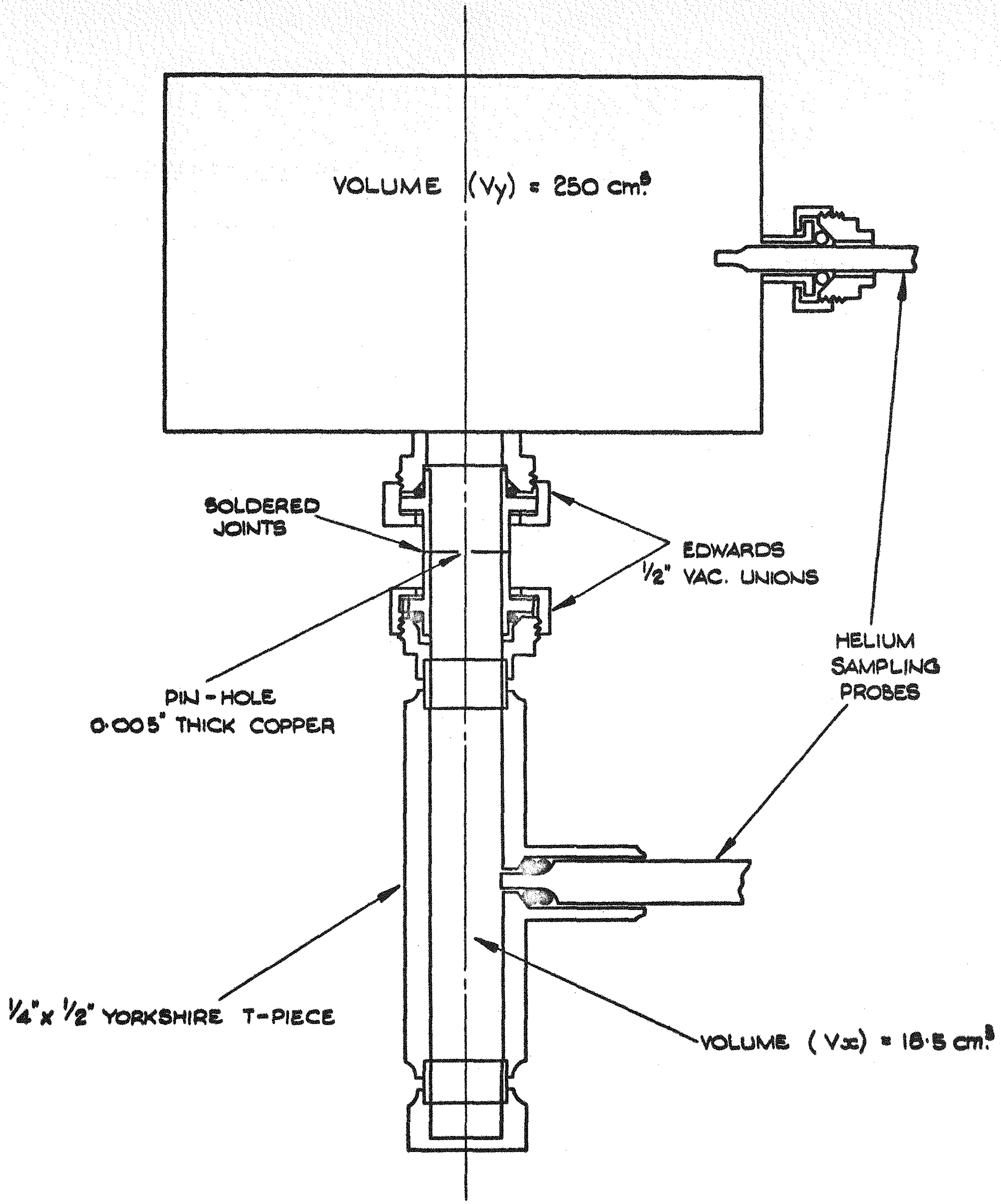
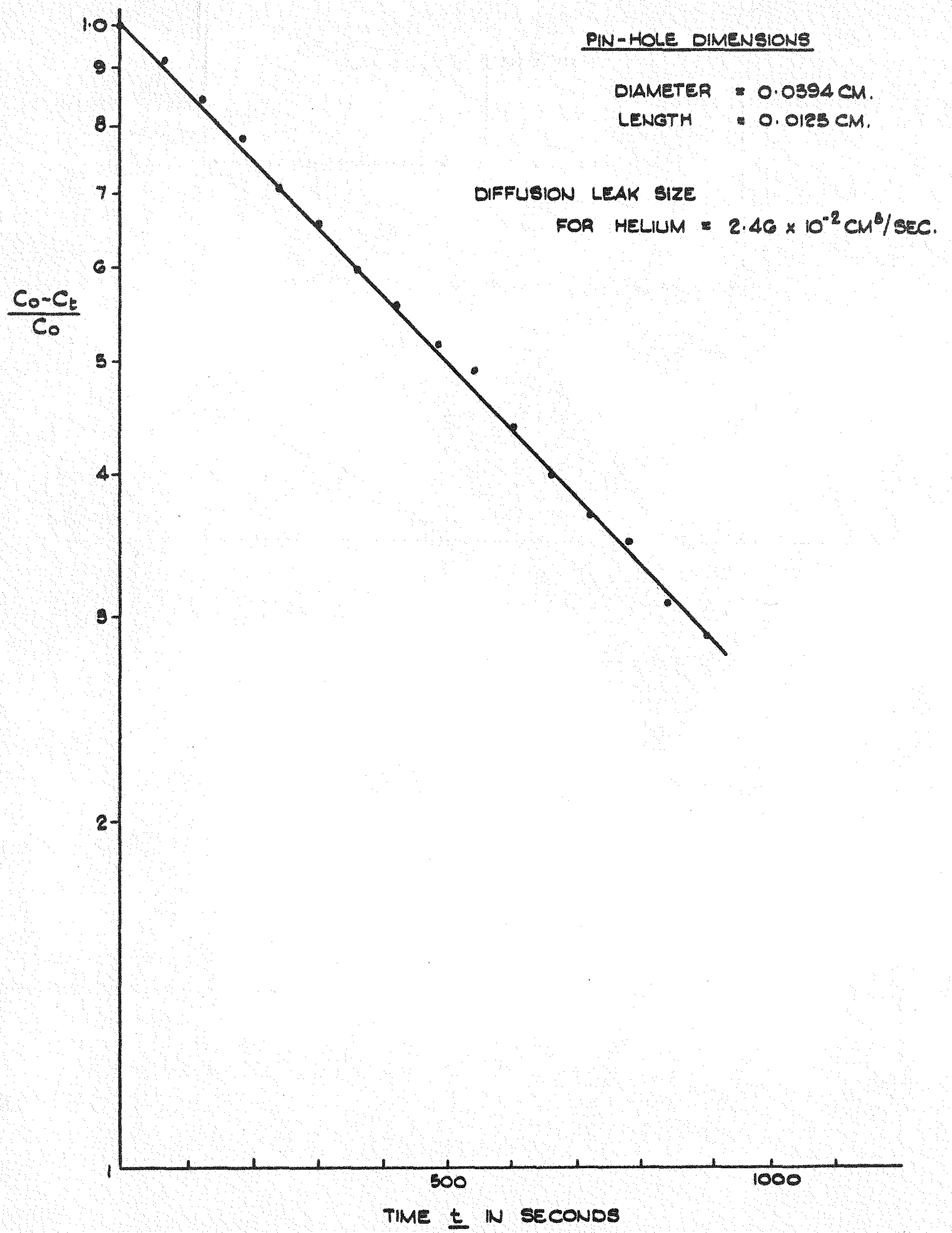


FIG. 7. APPARATUS TO MEASURE LEAK SIZE OF PIN-HOLES.



PIN-HOLE DIMENSIONS

DIAMETER = 0·0394 CM.
LENGTH = 0·0125 CM.

DIFFUSION LEAK SIZE
FOR HELIUM = $2{\cdot}46 \times 10^{-2}$ $CM^3/SEC.$

FIG. 8 SAMPLE CURVE OF HELIUM DIFFUSION THROUGH PINHOLES.

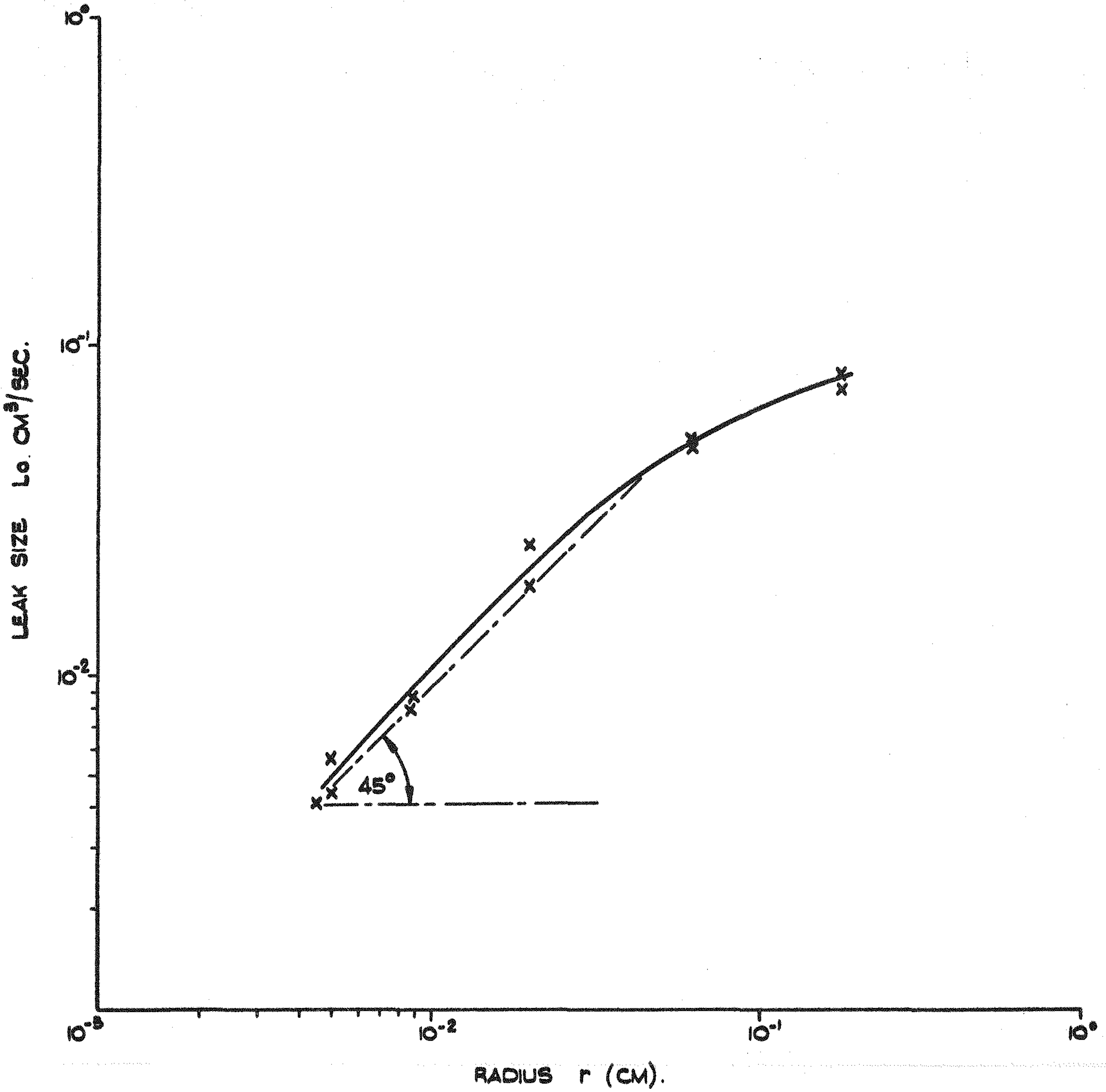
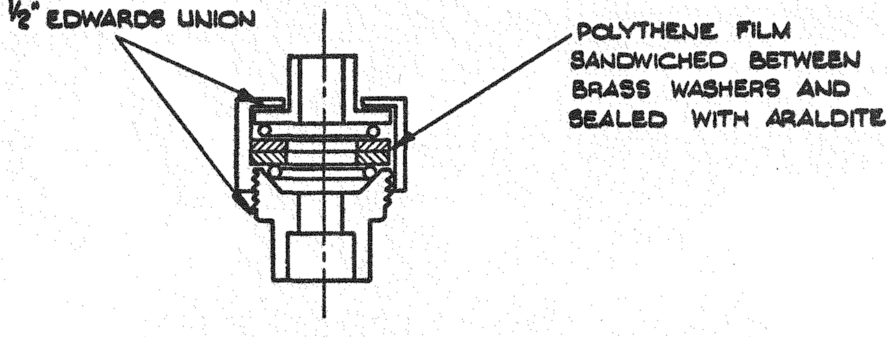


FIG. 9 CURVE OF LEAK SIZE VERSUS PINHOLE RADIUS FOR CONSTANT LENGTH.



DETAIL OF SAMPLE SUPPORT

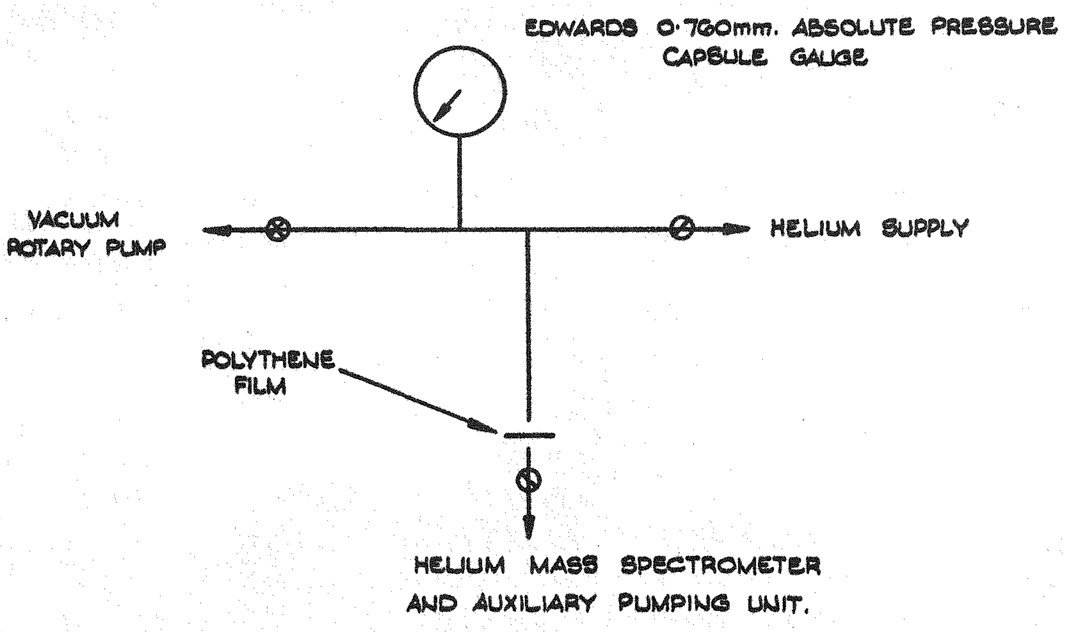
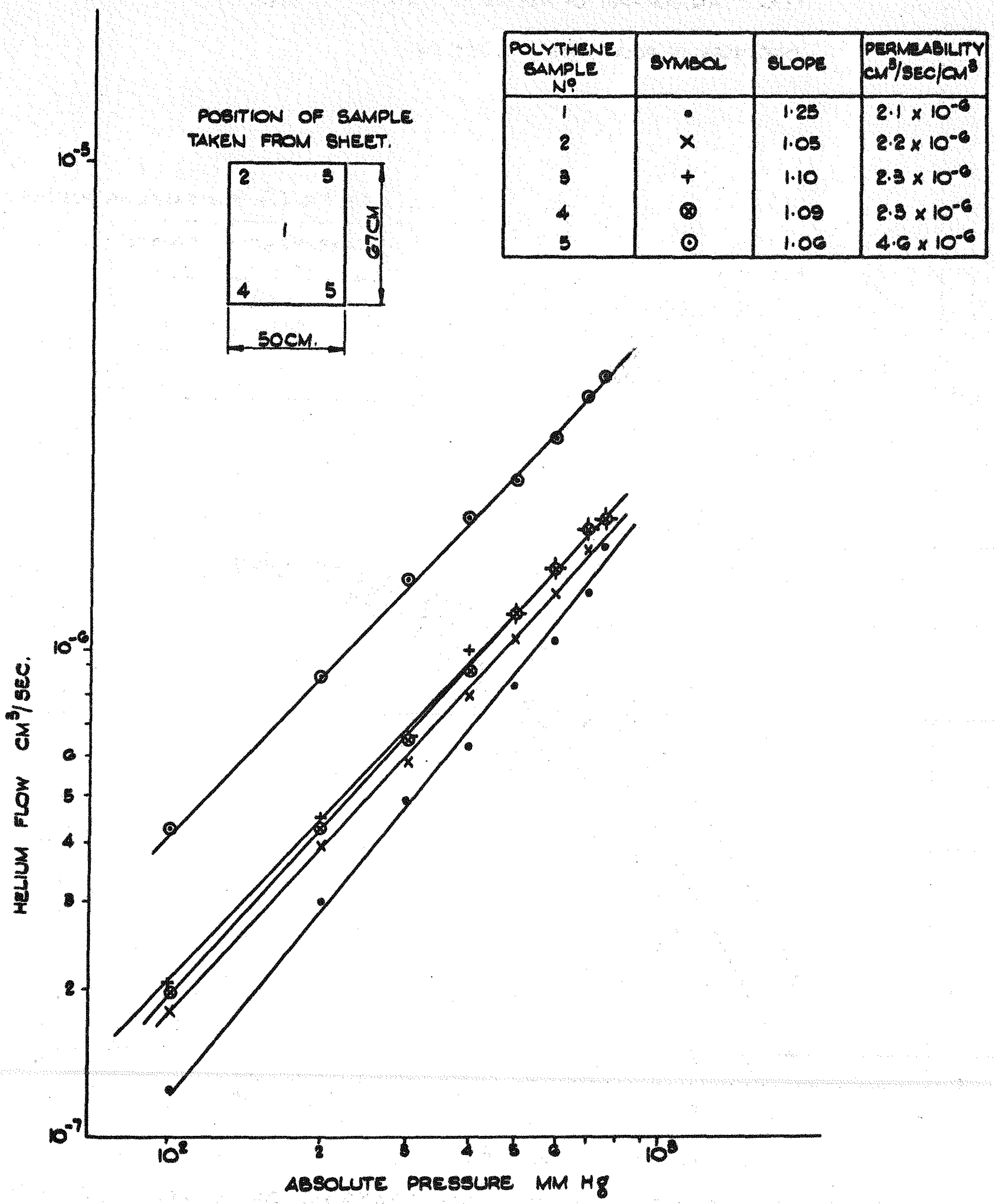


FIG. 10 APPARATUS TO MEASURE PERMEABILITY OF POLYTHENE WITH 100% HELIUM / VACUUM CONDITION.



POLYTHENE SAMPLE Nº	SYMBOL	SLOPE	PERMEABILITY CM³/SEC/CM³
1	•	1·25	2·1 x 10⁻⁶
2	×	1·05	2·2 x 10⁻⁶
3	+	1·10	2·3 x 10⁻⁶
4	⊗	1·09	2·3 x 10⁻⁶
5	⊙	1·06	4·6 x 10⁻⁶

FIG. 11 HELIUM FLOW THROUGH POLYTHENE (0·025 CM. THICK AREA 0·82 CM²) AS FUNCTION OF PRESSURE.

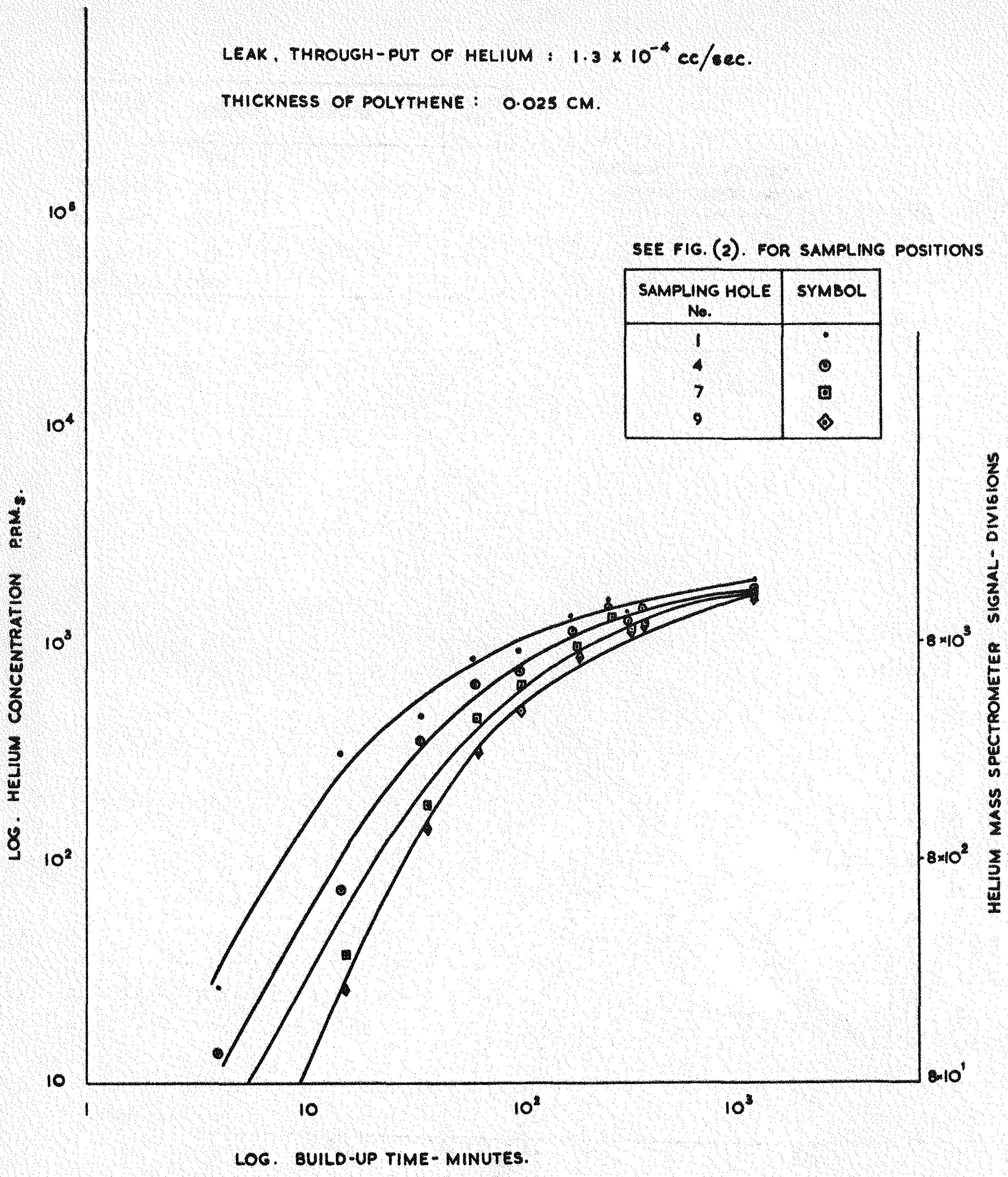


FIG. 12 BUILD-UP OF HELIUM CONCENTRATION BETWEEN POLYTHENE FILM AND STAINLESS STEEL FOR 1·3 X 10^{-4} cm.^{3}/s. LEAK.

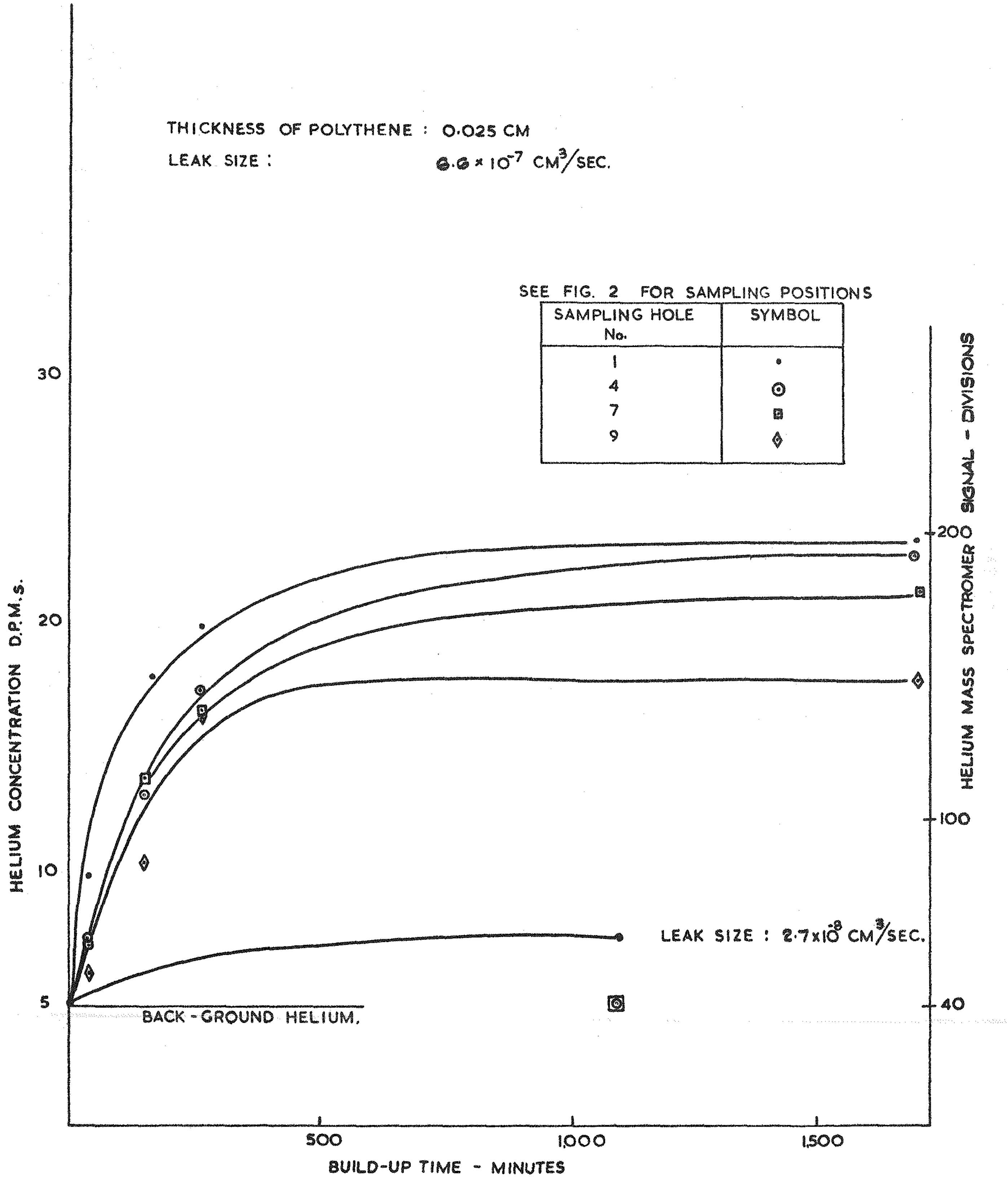


FIG. 13 BUILD-UP OF HELIUM CONCENTRATION BETWEEN POLYTHENE FILM AND STAINLESS SHEET FOR C.E.C. HELIUM LEAKS $6{\cdot}6 \times 10^{-7}$ cm.^{3}/s AND $2{\cdot}7 \times 10^{-8}$ cm.^{3}/s.