STUDIES OF HETEROGENEOUS TWO PHASE FLOW IN LARGE DIAMETER HORIZONTAL PIPELINES

A thesis presented for the Degree of

Doctor of Philosophy

by

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APPENDIX A

DETAILS OF PRESSURE TAPPING POINTS

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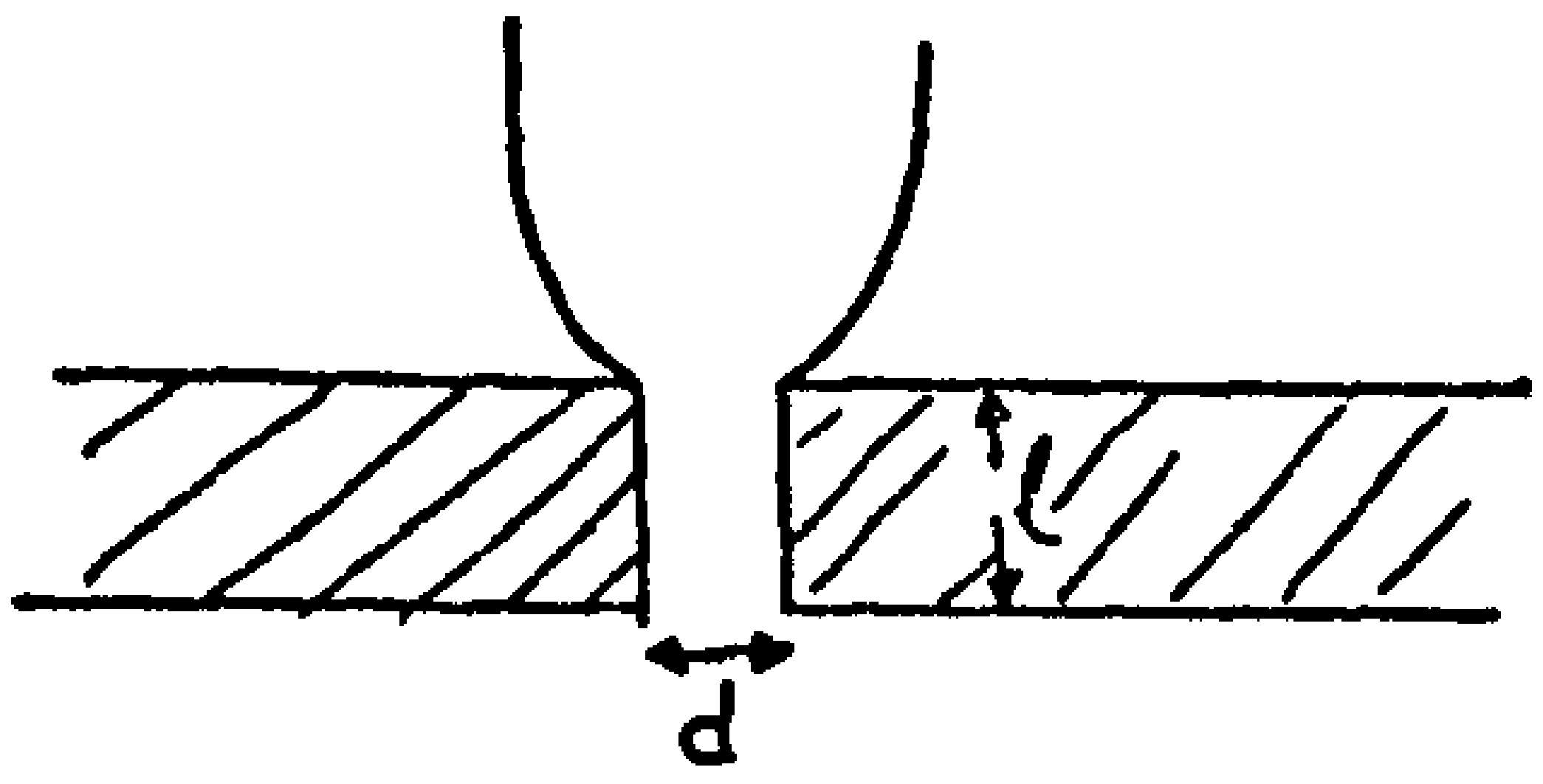
A.1 DESIGN OF PRESSURE TAPPINGS

Generally the magnitude of the error due to the hole size depends not only on the hole diameter 'd', but also on its depth 'ℓ', and on the geometry of the internal arrangement of the pressure connection (Ower and Pankhurst, 1966). Shaw (1960) studied the errors due to sharp edged holes of the type shown in the figure below. He found that the errors increased with the rates ℓ/d up to a value of $\ell/d = 1.5$ and thereafter remained fairly constant.

Thus for fully turbulent flow and for $\ell/d \geqslant 1.5$, the error is about three times the velocity head multiplied by the friction factor,

i.e. Error $\simeq 3\ \lambda.\ \frac{1}{2}\ \rho\ W^2$



For the large diameter tubes used in this project, the bosses used are detailed in Fig. A1 and minimised the measuring errors to an estimated 0.25%. The errors in pressure distribution data, and hence pressure gradient will be less than this since the pressure tappings were identical.

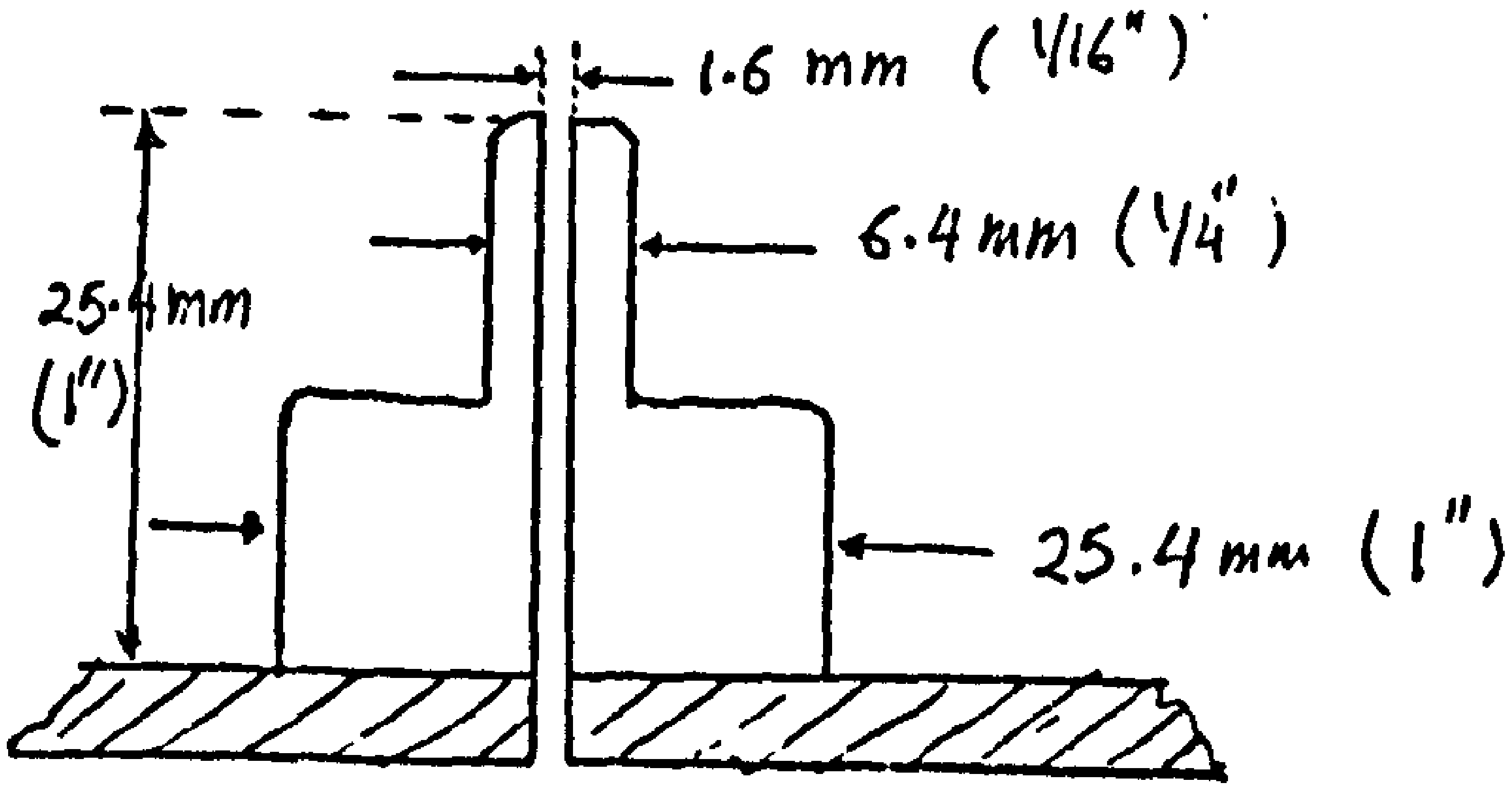


FIG.A1 PRESSURE TAPPING POINT ASSEMBLY

APPENDIX B

FURTHER DETAILS OF AIR AND WATER FLOW RATE MEASUREMENTS

APPENDIX B FURTHER DETAILS OF AIR AND WATER FLOW RATE MEASUREMENTS

B.1 GENERAL DESIGN OF ORIFICE PLATES

The design calculations for the orifice plates presented in this Appendix follow from B.S. 1042, Pt. 1 and Pt. 3, 1964, and are presented in the same units as the Standards. This gives the mass flow rate W (lb/hr) of a fluid of density ρ (lb/ft^3) through an orifice of aperture diameter d (inches) situated in a pipe of diameter D (inches) at a head loss of h (inches of water) as:

$$W = 359.2\ C\ Z_R\ Z_D\ \epsilon\ d^2 \sqrt{\rho}\ \sqrt{h} \tag{B1}$$

where

Z_R, Z_D = correction factors for Reynold's number and diameter of pipe, respectively.

ϵ = Expansibility factor (= 1 for liquids)

C = Basic coefficient.

E = Velocity of approach coefficient

$= 1/\sqrt{1-m^2}$, where $m = d^2/D^2$

B.2 AIR FLOW ORIFICE METER

Rough calculations were carried out based on the desired range of conditions ($\sim$ 10 cusec free air) and showed that a value of d = 1.625" was suitable. This allowed an overlap on the range of air flow rates measured by the rotameters.

Under these conditions, equation (B1) reduced to

$$W = 778.36 \; \epsilon \; Z_R \sqrt{\rho} \sqrt{h} \qquad \text{(B2)}$$

where

Z_D was taken as 1.0069, i.e. equivalent to 'new steel' pipe characteristics, and the density of dry air ρ (lb/ft^3) upstream the orifice plate was related to the upstream absolute pressure P (lbf/in^2) and temperature T (^{o}F) by the equation

$$\rho = 2.7 \; (P/T) \qquad \text{(B3)}$$

substituting in equation (B2) then gives

$$\sqrt{\frac{T}{P}} \; W = 1278.98 \; \epsilon \; Z_R \sqrt{h} \qquad \text{(B4)}$$

This relationship is shown in Fig. B1 for values of $\epsilon = Z_R = 1$. To correct for Reynold's number and expansion effects, the following procedures were adopted as being suitable for digital computers.

(i) Reynold's Number Correction Factor, Z_R:

Using the graph supplied in B.S.1042 for the Reynold's Number correction factor as a function of 'm' and 'Re' where 'Re' was defined as

$$Re = \frac{W}{15.8 \mu d} = 213.1 \; (\frac{hr}{lb}) \; . \; W \; (\frac{lb}{hr}) \qquad \text{(B5)}$$

and cross plotting the results yielded a direct relationship between 'Re' and 'Z_R'. This is shown in Fig. B2. A polynomial equation of 3rd order was found adequate to

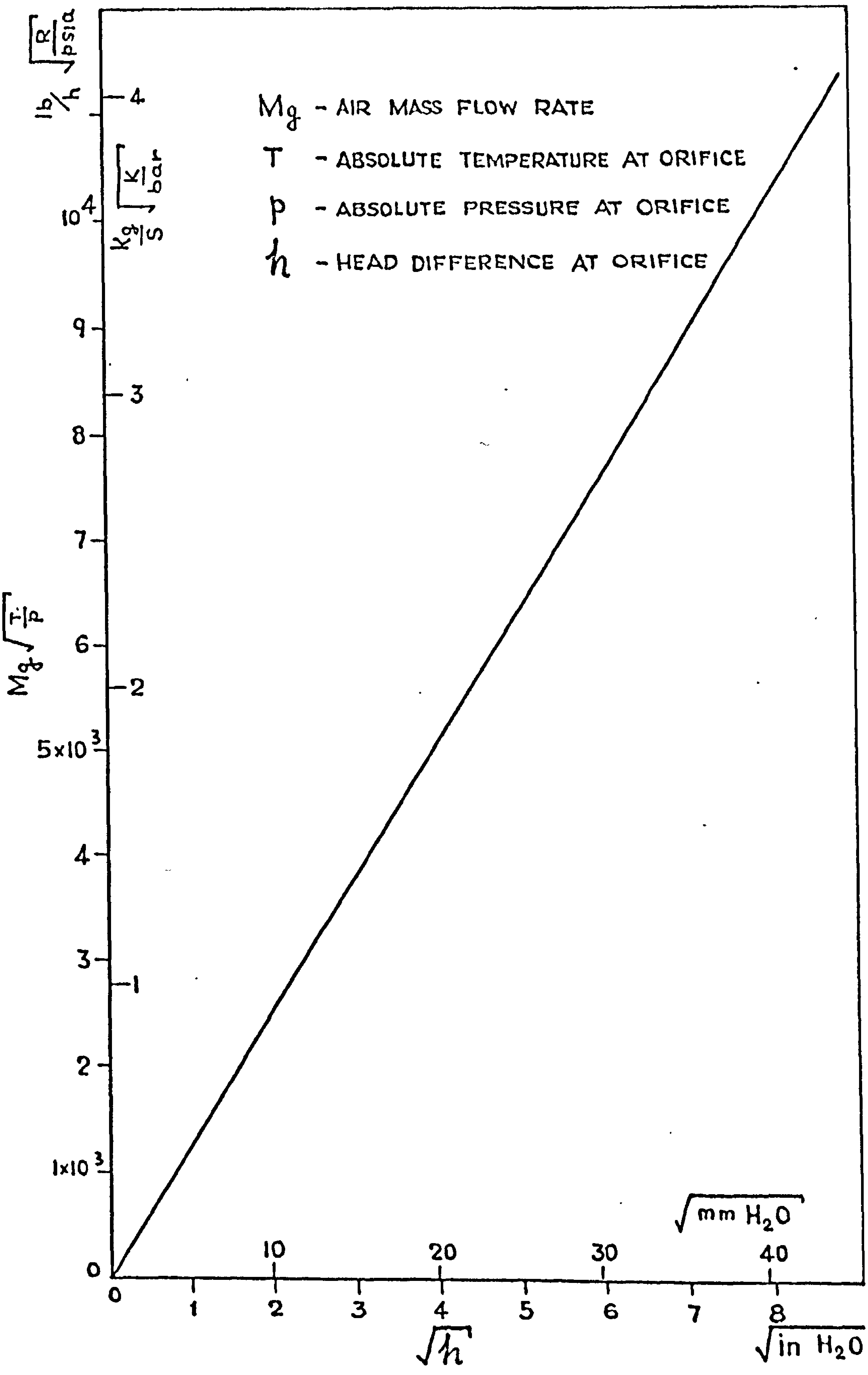
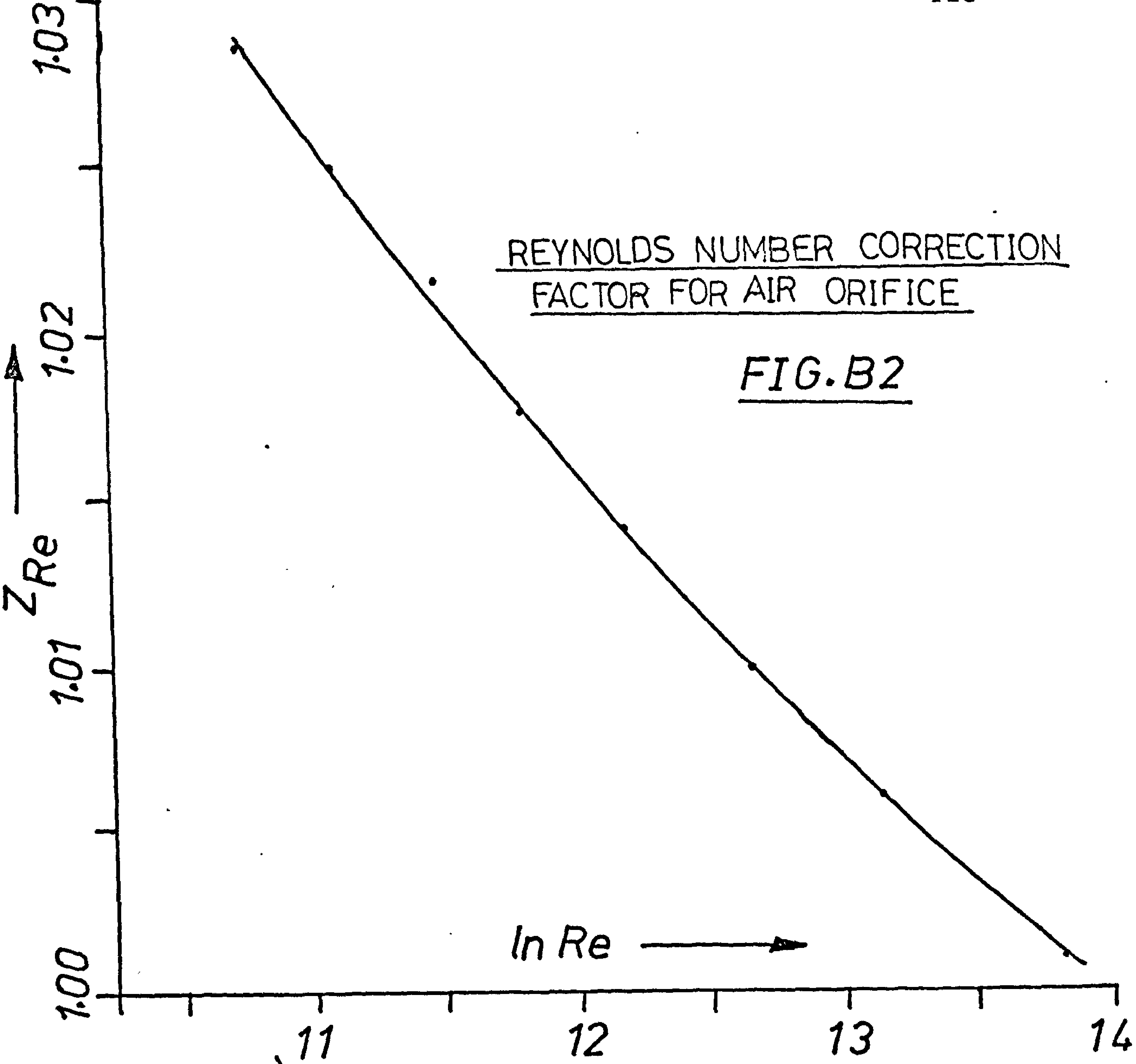


FIG. B1 CHARACTERISTIC FOR AIR FLOW ORIFICE (B.S. 1042)



REYNOLDS NUMBER CORRECTION FACTOR FOR AIR ORIFICE

FIG. B2

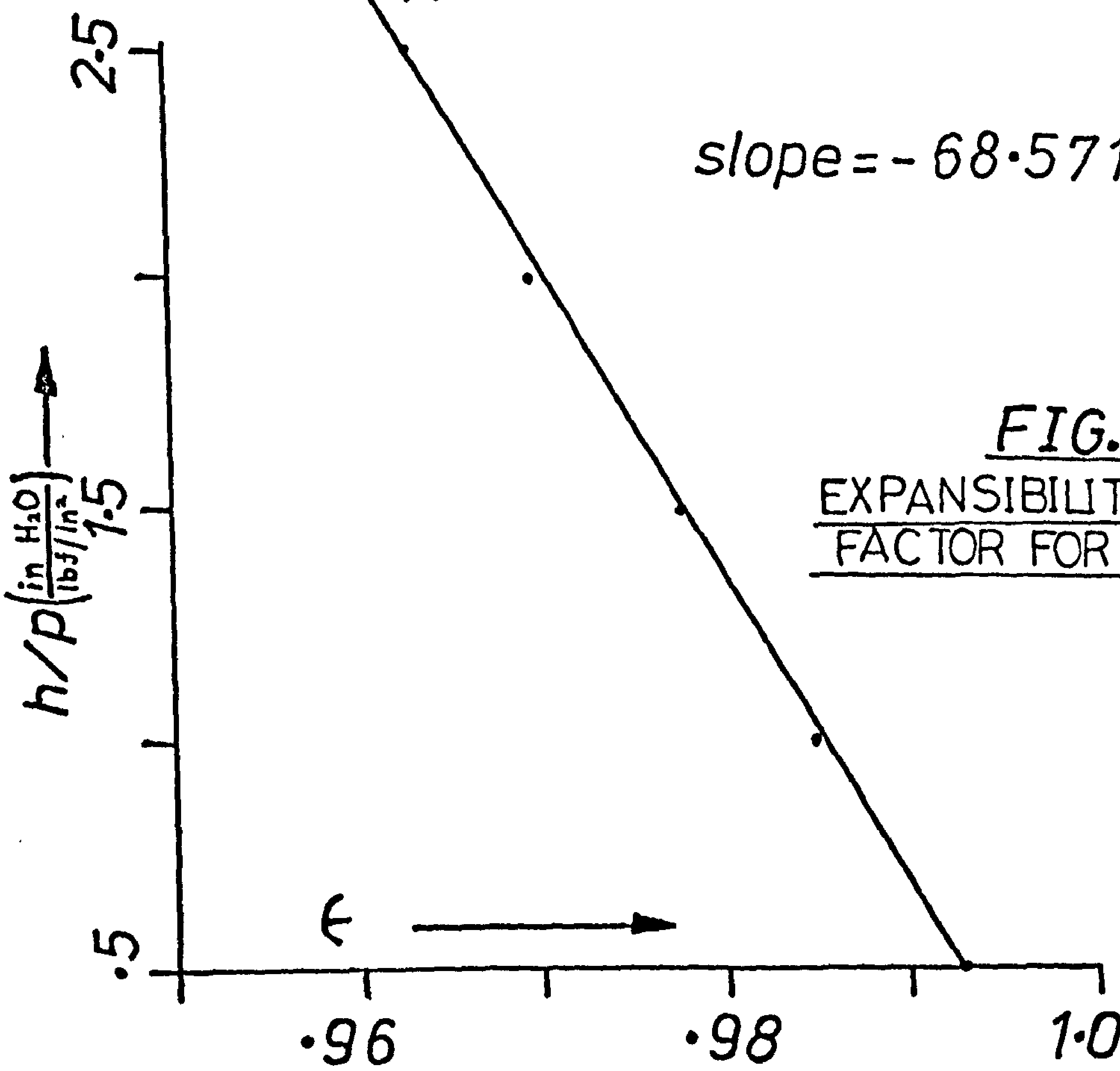


FIG. B3

EXPANSIBILITY CORRECTION FACTOR FOR AIR ORIFICE define the characteristic, the coefficients being,

$a_0 = .99481525$ $a_1 = .0326579$

$a_2 = -.00416899$ $a_3 = .0001302259$ (B6)

(ii) Expansibility Correction Factor, ϵ :

For this factor the B.S. 1042 presents a complex graph giving the expansibility factor of the gas in terms of the quantity (h/p) inches $H_2O/(lbf/in^2)$, where p is the upstream pressure, the isentropic index (taken as 1.4) and the quantity 'm'. Suitable cross plotting again enabled this correction factor to be correlated against the quantity h/p as hhown in Fig. B3. The relationship is linear and can be defined as

$$\epsilon = 1.0 - .01458333\ (h/p) \qquad \text{(B7)}$$

Hence, equations B4, B5, B6 and B7 could be used to determine the air flow rate using the orifice meter.

The orifice plate was manufactured from $\frac{1}{8}$" thick brass plate, according to B.S. 1042 and the dimensions measured accurately in the Metrology Laboratory to within 1/10000 of an inch. The measurements obtained were

(i) Throat diameter:

d = 1.6256", 1.6257" at two right angle radii

$\therefore$ d = 1.62565" ± 0.00005"

(B.S. 'd' should be within ± 0.0005d, or ± 0.0008")

(ii) Orifice Bore Parallelity:

This was done by positioning the plate on a travelling microscope stage (horizontal) and scanning vertically. The plate was turned upside down and the process was repeated.

(iii) Edge Thickness of Orifice:

Manufactured = 0.038"
(B.S. = 0.04")

(iv) Angle of Level of Orifice:

Manufactured = 49°
(B.S. = 30° - 45°)

(v) Thickness of Plate:

Manufactured = 0.0913"
(B.S. = 0.10" max.)

(vi) Orifice Edge:

Orifice edge was free from burs or wire edge. The radius of curvature was determined using 'Replica', magnification 20X and a radius gauge. The radius of curvature was 0.06", hence

Manufactured = 0.003"
(B.S. = 0.00055")

This deviation could cause a negative error of $\sim$ .83% as calculated using B.S. 1042, Pt. 3, 1964.

To ensure that the orifice was concentric with the 2" steel pipe, a recess was machined in the downstream flange to accommodate the plate. Slightly greased paper joints were used to seal the plate from both sides. Prior to that, two bosses machined and threaded to take two $\frac{1}{4}$" needle valves were carefully welded on the pipes so that their centres were distance D and D/2 from the flanges. The bosses were machined to the curvature of the pipe (2.25" OD) and a $^1/16$" hole drilled in each and deburred.

A regulating valve was installed upstream of the orifice plate to regulate the pressure. This was located 240 pipe diameters upstream of the plate, well within B.S. 1042 requirements.

A 2.5m long copper constantan thermocouple was used to measure the air temperature upstream of the orifice plate. The hot junction was inserted into the air stream and the cold junction immersed in a mixture of ice and water at 0°C in a thermos flask. The thermocouple was calibrated using a water bath, with a stirrer and standard thermometers. The emf-temperature characteristics obtained is shown in Fig. B4. Over the range of interest, the characteristics could be expressed in terms of

$$T\ (^\circ C) = \frac{24}{0.95} \cdot \text{emf (mV)} \qquad \text{(B8)}$$

B.3 WATER FLOW ORIFICE METER

The orifice plate was designed, manufactured, and installed according to B.S. 1042 and the following are the main geometric design parameters that entered directly in the mass flow rate calculations:

$D = 5"$, $d = 3"$, $E = 1.072$

$C = 0.608$, $Z_D = 1.003$, $\mu = 0.013$ Poise

$\rho = 62.4$ lb/ft^3 and $\epsilon = 1$

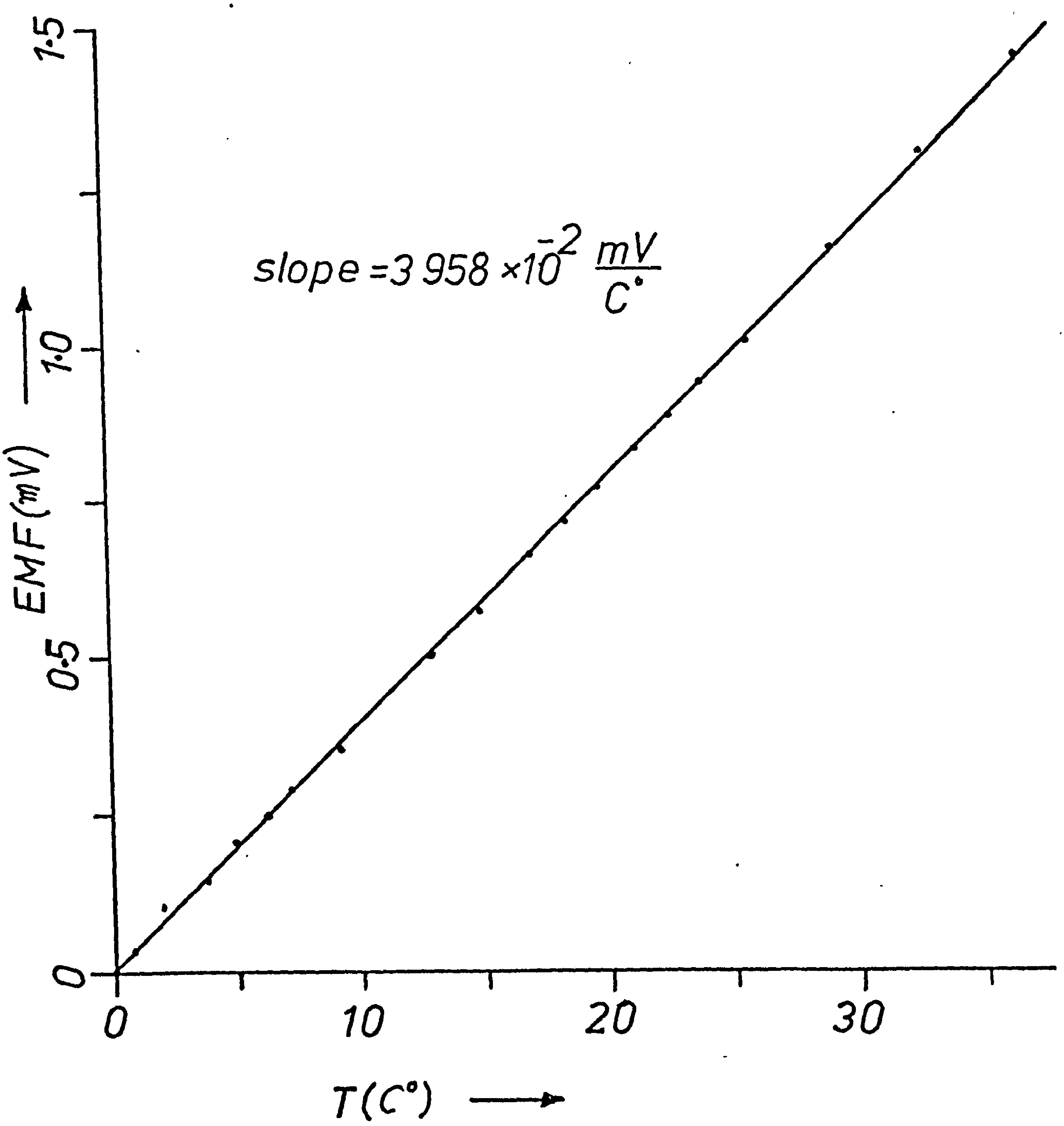


FIG. B4 THERMOCOUPLE CALIBRATION CURVE

The design equation reduces to

$$W\ (\text{lb/h}) = 16694.4\ Z_R \sqrt{h} \tag{B9}$$

where Z_R was defined earlier as a correction factor based on 'Re' defined by

$$\text{Re} = \frac{W}{15.8\ \ d} = 1.62285\ W$$

with W in lb/h.

The water flow orifice was calibrated in a closed loop test facility in the Departmental Hydraulics Laboratory in the form of an 'in-situ' assembly. The assembly consisted of the 76.2 mm (3") diameter orifice plate fitted between the flanges of two lengths of 3.05m (10 ft) galvanised steel pipes and comprised part of the water flow line. During the calibration, corresponding measurements of flow rate and pressure difference were taken. Flow rate measurements were made in terms of the quantity of water collected in a calibrated tank in a given time and pressure difference readings from a pressurised, inverted air-water or mercury-water manometer. In total, almost a hundred test runs were conducted over a range of flow rates.

The results are plotted as shown in Fig. B.5, on a basis of Q versus $\sqrt{h}$, and the calibrated curve for the orifice obtained. The low of the curve (a straight line through the origin of the plot mentioned) was derived as

$$Q(\text{ft}^3/\text{s}) = 0.04833 \sqrt{h(\text{cm})} \tag{B10}$$

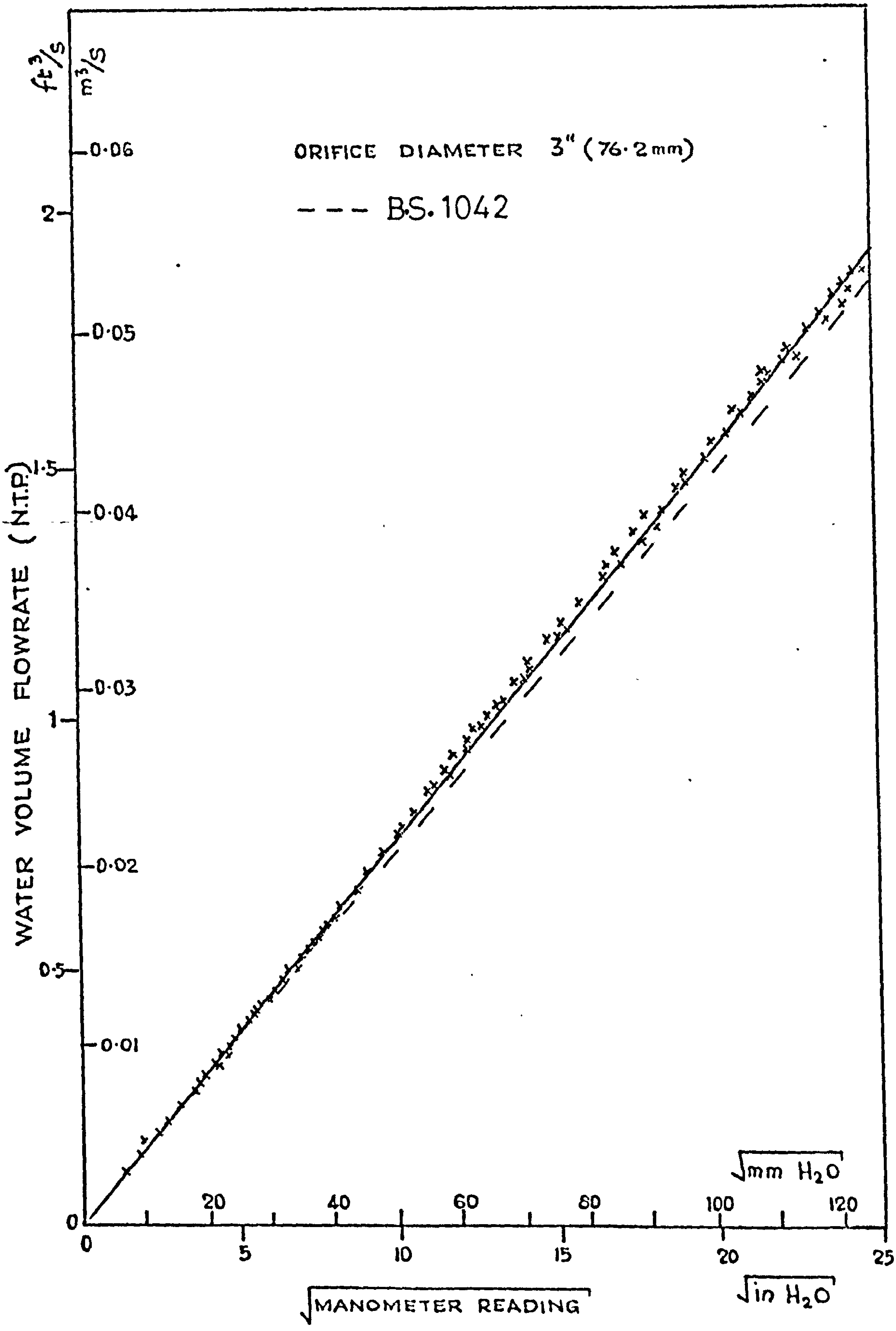


FIG.B5 IN-SITU CALIBRATION CHARACTERISTIC FOR WATER FLOW ORIFICE.

and this was used in subsequent tests. This line corresponded with the B.S. 1042 characteristic line (shown dotted), as can be seen, the calibration test results agree closely with this, the maximum deviation being 3%.

B.4 AIR FLOW MEASUREMENTS BY ROTAMETERS

Calibration curve for the rotameters used were obtained from the charts supplied by the manufacturer. The process involved the calculation of two parameters, I and F_t, then, by using the charts supplied (Fig. B.6) and cross-plotting, a graph relating volumetric flow rate with float height could be obtained. The expressions for I and F_t were:

$$I = \mathrm{Log}_{10}\left[K1 \,.\, \nu 1.10^3 \sqrt{\frac{\sigma\rho}{W(\sigma-\rho)}}\right] \qquad \text{(B11)}$$

$$F_t = K2 \sqrt{\frac{W(\sigma-\rho)}{\sigma\rho}} \qquad \text{(B12)}$$

and

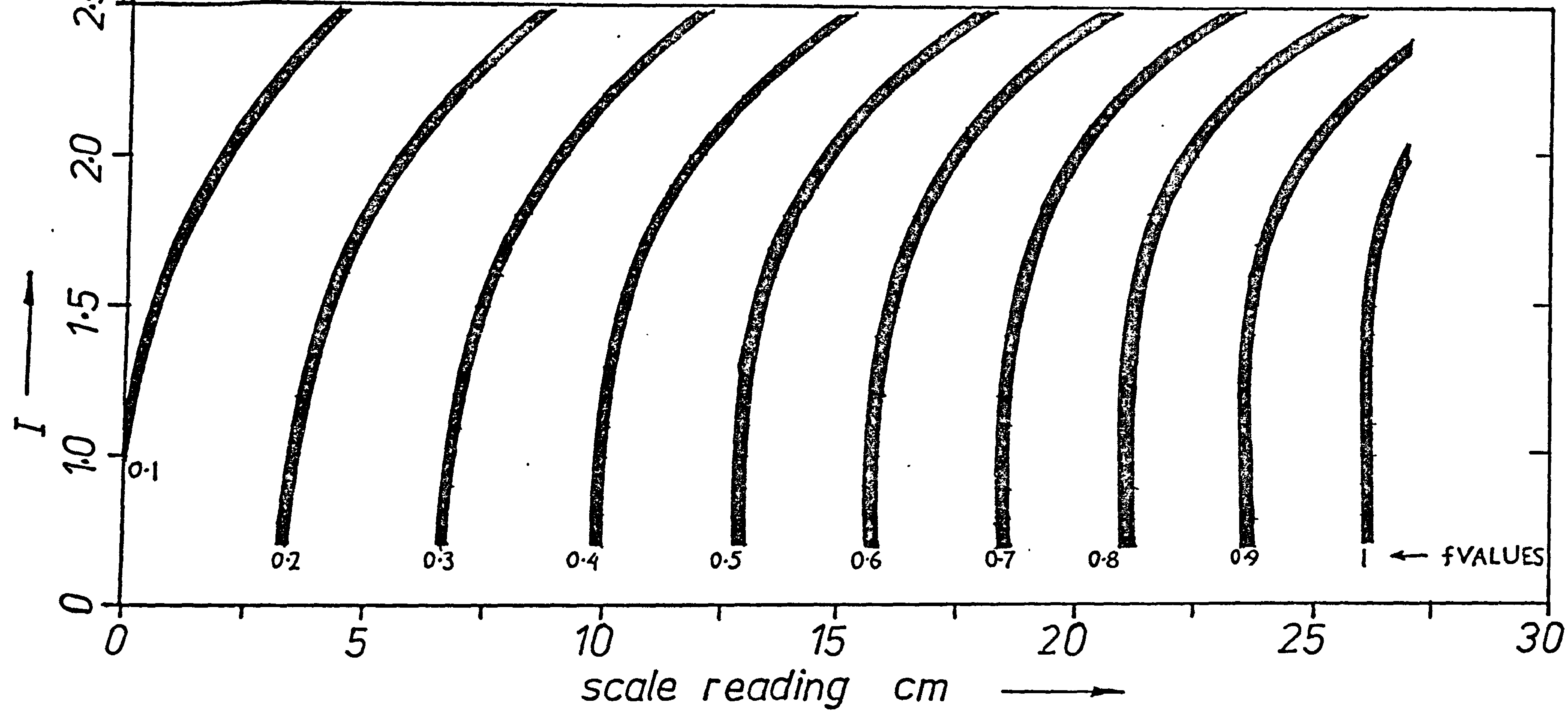
$$F = f.F_t \qquad \text{(B13)}$$

The symbols are defined at the end of this section.

Calibration graphs were constructed for particular values of absolute pressure at a temperature of 19°C giving the free volumetric flow rate (in Lit/min) versus the scale reading in cm. These are shown in Fig. B.7, for pressures of 1.5, 2 and 2.5 bar absolute.

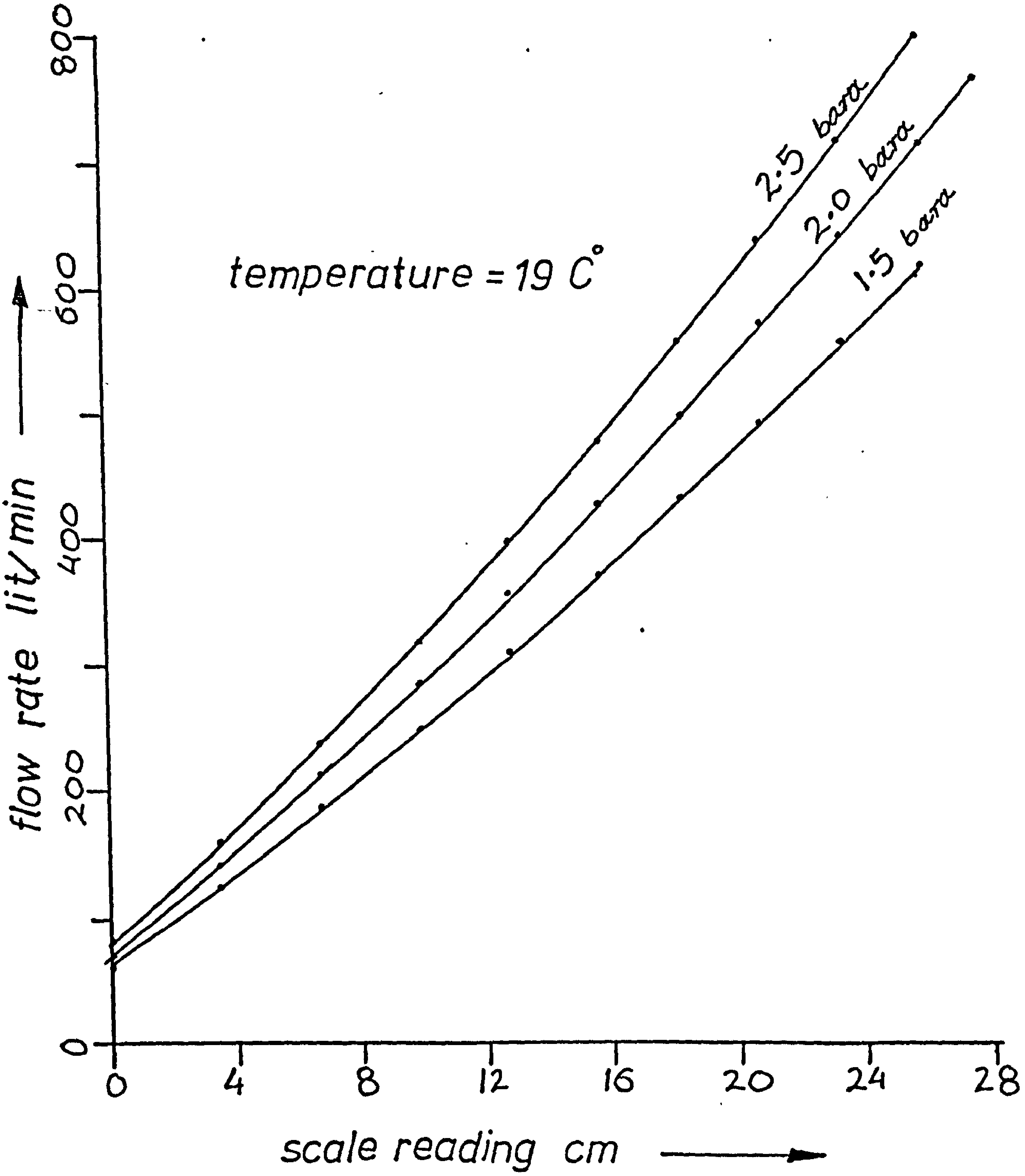
The 2 bar curve was expressed in a polynomial of the form,

DYNAMIC CHARACTERISTICS OF METRIC SERIES ROTAMETER SIZE 35



FIG· B6

K1=1·5
K2=3·33



FIG·B7 MANUFACTURERS CALIBRATION (ROTAMETER)

$$y = \sum_{i=1}^{N} a_i x_i$$

and the best polynomial to fit the curve was determined using a computer library subroutine. The coefficients obtained were as follows,

$$a_o = 69.798 \qquad a_1 = 20.24$$
$$a_2 = 0.0253 \qquad a_3 = 0.0124 \qquad \text{(B14)}$$
$$a_4 = 0.000274$$

To convert the flow rates from, say 2 bar absolute and 19^{o}C to the operating conditions at the test section, a correction must be made for pressure and temperature at the operating conditions. This was done through the equation

$$Q_{T_g,O} = Q_{CALIBRATION} \frac{\sqrt{\rho_{CALIBRATION} \; \rho_{T_g, p_g}}}{T_{g,1}} \qquad \text{(B15)}$$

which could be used in conjunction with the calibration graph.

The calibration characteristics obtained from the manufacturer's data were checked by calibration tests using a pitot static tube. The calibration apparatus is shown in Fig. B.8 and involved an air line 53 mm nominal bore, 6m long. The fan, driven by a 1 HP motor, promoted air flow along the pipe, the flow being controlled by a screwed disc at the fan outlet. The pitot was situated at the tube centreline and the centre constant was taken as 1/1•235 (turbulent flow). The

FIG. B8 ROTAMETER CALIBRATION SET UP

comparison is shown in Fig. B.9, and as can be seen, agreement is obtained to within 10% (usually much better than this), part of the difference perhaps being due to the value of the centre constant used.

The equation of the best line through the data is

$$Q_{Pitot}\ (M^3/s) = 0.90667 \times Q_{Rot.}\ (m^3/s) + 0.7013 \times 10^{-3} \qquad (B16)$$

and was used to correct the rotameter readings.

NOMENCLATURE:

W : Weight of float in gm.

σ : Mean density of float in gm/cc.

ρ : density of fluid at working temperature and pressure in gm/cc

ν : kinematic viscosity of fluid at working conditions in stokes.

F_t : Theoretical capacity in lit/min, based on no change in Reynold's number.

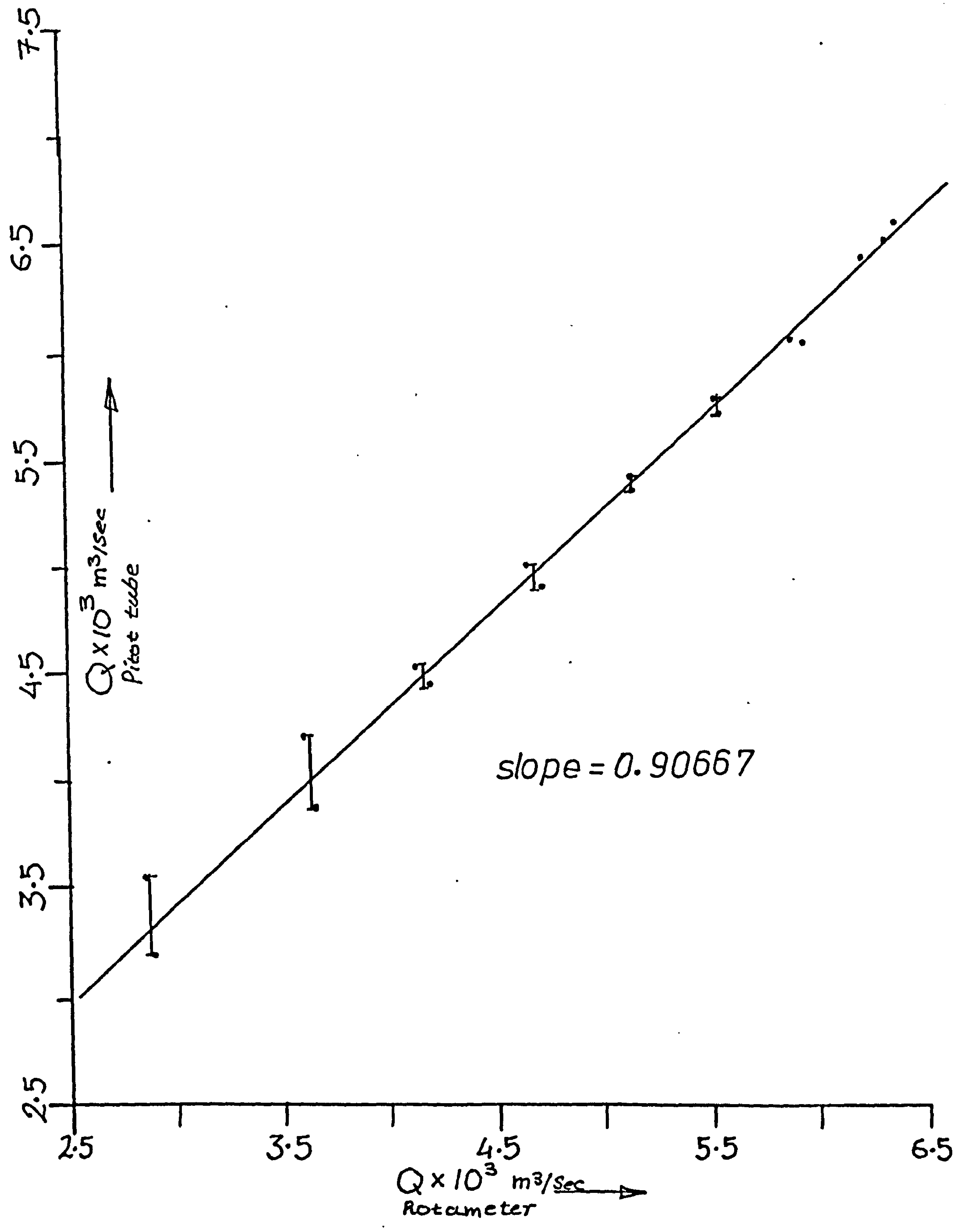
F : Actual flow in lit/min.

f : Fraction of flow rate, $= F/F_t$ and goes from 0-1.

K1,K2: Constants which depend on the size of the rotameter used. For Metric 35, which was the size we used, these are 1.5 and 3.330, respectively.

I : Ordinate of calibration charts.

$Q_{T,P}$: Volumetric flow rate at temperature T and pressure P.



FIG·B9 ROTAMETER CALIBRATION

APPENDIX C

PURGING PROCEDURES AND PRINCIPLES

APPENDIX C PURGING PROCEDURES AND PRINCIPLES

When measuring pressure, it is important to keep the pressure lines (when filled with liquid) free from bubbles which could cause errors due to gravity, capillary action, etc. This can be difficult with two phase flow where pressure fluctuations or flow instabilities tend to force the lighter phase into the pressure line where it is trapped.

It is necessary, therefore, either to purge the pressure lines before readings are taken or, as was done here, to maintain a continuous purge of the flow lines with liquid. In doing this, one has to be aware of the limitations of this technique and the corrections which are necessary in order to determine accurately the static pressure. Some of these are discussed later.

The general philosophy was as follows:

(i) The purging lines were kept pressurised at a pressure which was at least three times the maximum working pressure in the line. The water mains pressure was found to be quite adequate.

(ii) The purging flow rate was kept as small as possible to reduce the friction pressure loss at the tapping point hole since this had to be corrected for.

(iii) The length of the connecting pipe from the purging inlet/manometer junction to the pressure tapping point was made the same for all pressure tapping points so that all corrections were similar.

(iv) The losses across the tapping points should be similar which means each tapping point has an equal share of the total purging flow rate.

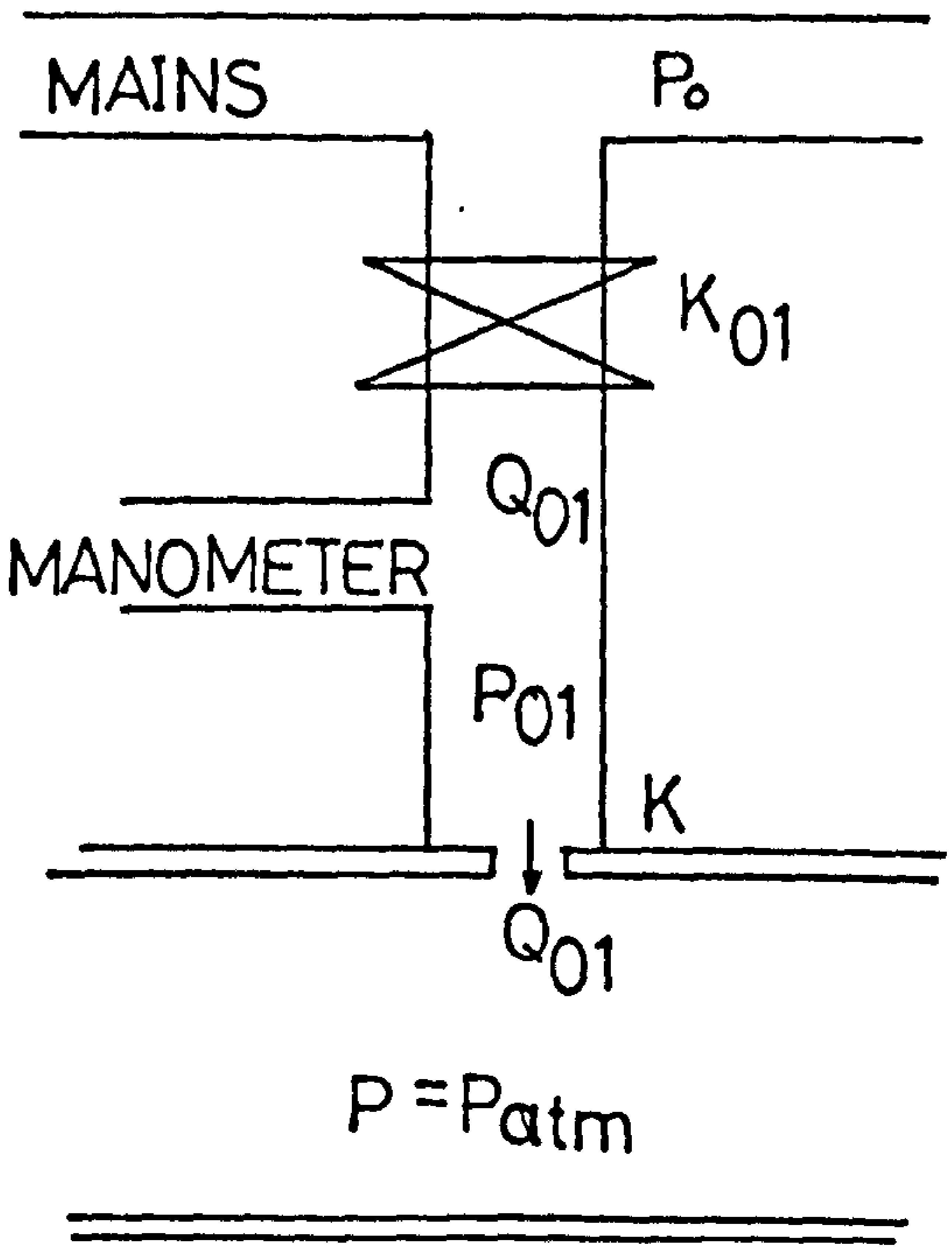
(v) Correction terms were determined at atmospheric conditions with the tube empty. The capillary effect in the 1.6 mm (1/16") hole was small and hence neglected.

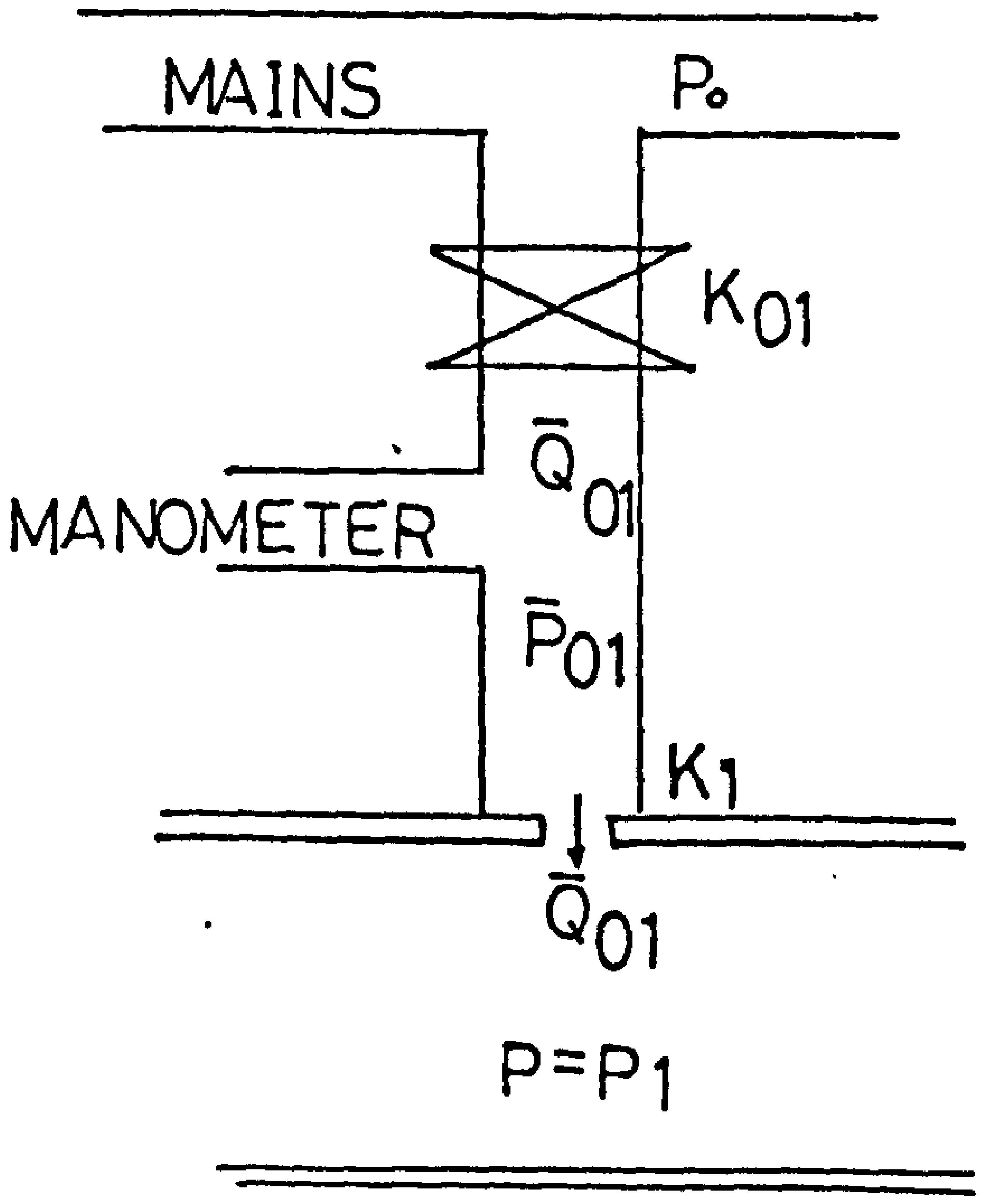
(vi) The purging rate to each pressure tapping point was controlled by a clamp mounted on the plastic tubing, these proved very reliable.

The total purging rate was measured using a rotameter and was always kept below 10 gal/h. The supply line was throttled to minimise mains pressure fluctuations. The total purging flow was controlled to within ± 1.5% of the atmospheric pre-testing set valve.

An analysis of the effects of purging can be made as follows:

1. STATIC EFFECTS





For the arrangement shown above, neglecting losses in the connecting tubes, one can write

(a) For atmospheric conditions:

$$P_o - P_{o1} = K_{o1}\, Q_{o1}^2 \qquad \text{(C1)}$$

$$P_{o1} - P_{atm} = K_1\, Q_{o1}^2 \qquad \text{(C2)}$$

(b) At pressure P_1:

$$P_o - \bar{P}_{o1} = K_{o1}\, \bar{Q}_{o1}^2 \qquad \text{(C3)}$$

$$\bar{P}_{o1} - P_1 = K_1\, \bar{Q}_{o1}^2 \qquad \text{(C4)}$$

From (C1) and (C3)

$$\left(\frac{\bar{Q}_{o1}}{Q_{o1}}\right)^2 = \frac{P_o - \bar{P}_{o1}}{P_o - P_{o1}} \qquad \text{(C5)}$$

From (C3) and (C4)

$$\left(\frac{\bar{Q}_{o1}}{Q_{o1}}\right)^2 = \frac{\bar{P}_{o1} - P_1}{P_{o1} - P_{atm}} \qquad \text{(C6)}$$

$$\therefore \quad \frac{\bar{P}_{o1} - P_1}{P_{o1} - P_{atm}} = \frac{P_o - \bar{P}_{o1}}{P_o - P_{o1}} \qquad \text{(C7)}$$

But, since

$$\bar{P}_{o1} - P_1 = \rho g\, h_t$$

and

$$P_{o1} - P_{atm} = \rho g\, h_a$$

where h_t is the true head loss across the hole and h_a is the corresponding head loss at atmospheric conditions.

Equation (C7) becomes

$$h_t = h_a \frac{P_o - \bar{P}_{ol}}{P_o - P_{ol}}$$

Since most of the data were taken under settled conditions, mostly at tappings no. 8 and no. 14, then

$$h_{8t} = h_{8a} \frac{P_o - \bar{P}_8}{P_o - P_8} \qquad (C8)$$

and

$$h_{14t} = h_{14a} \frac{P_o - \bar{P}_{14}}{P_o - P_{14}} \qquad (C9)$$

Bearing in mind that

$$\bar{P}_{14} = \bar{P}_{18} - \left(\frac{\Delta P}{\Delta Z}\right) \cdot (Z_{14} - Z_8) \qquad (C10)$$

Equation (C10) in conjunction with (C8) and (C9) show that the two tappings get different attenuations. Consider the extreme conditions of

(i) Low pressure:

i.e. $P_o \gg \bar{P}_8$ and $P_o \gg P_{14}$ also

$\bar{P}_8 \simeq \bar{P}_{14}$, hence

$h_{8t} \simeq h_{8a}$

$h_{14t} \simeq h_{14a}$

The only point of concern here is that however small the attenuation may be it could be comparable to the $\Delta P/\Delta Z$ values. To minimise this effect, the purging head losses were made almost equal and comparatively small when compared to no purge readings. Also 'P_o' was kept large (almost at mains pressure).

(ii) High pressure:

Here $\bar{P}_8$ and $\bar{P}_{14}$ are nearer to P_o (maximum pressure $\sim$15 psig) and attenuation to the values of h_{8a} and h_{14a} could happen. By keeping the purging head losses to a minimum, and since the pressure drop was quite large, the effect was completely negligible.

2. DYNAMIC EFFECTS

The arguments presented in the previous section were based on static conditions. During actual tests, the effect of the interaction between the velocity profiles in the pipe and that at the exit of the 1.6 mm (1/16") hole due to purging is not fully understood. However, by minimising the purging flow rate, it was hoped that this effect would be negligible. Also by making the purging rate through the different tappings similar, the interaction between the two profiles and the effect on the measurement of static pressure at each tapping would be identical. This effectively meant that the errors due to the dynamic interaction could be neglected as far as the pressure drop measurements were concerned.

APPENDIX D

THEORY AND APPLICATIONS OF SCINTILLATION COUNTERS AND IONISATION CHAMBERS FOR VOID FRACTION MEASUREMENTS

APPENDIX D THEORY AND APPLICATIONS OF SCINTILLATION COUNTERS AND IONISATION CHAMBERS FOR VOID FRACTION MEASUREMENTS

D.1 INTRODUCTION

Radiations interact with matter in different ways and are mostly accompanied by ionisation. Particles (i.e. He^{++}, β^-, n, etc.) interact directly to produce ions. Photons (i.e. γ-rays, x-rays, etc.), on the other hand may interact in one of several ways:

A - Photoelectric Effect:

This is important at low energies (up to 1 Mev) and for high atomic number materials. The entire energy of the photon is absorbed and an orbital electron is ejected with a K.E. equal to that of the photon, less the work required to overcome the attraction potential of the atom (normally called the work function).

B - Compton Interaction:

At high energies the photon gives a portion of its energy to a substantially free electron in a manner somewhat resembling the billiard ball type of collision. Here the photon is not destroyed but rather reduces its energy. In lead, and for γ-ray energies of 0.5-5 Mev, this is the most probable process of interaction.

C - Pair Production:

A photon of energy $>$1.02 Mev (twice the rest mass of an electron) is converted in the vicinity of a nucleus into an electron β^- and a positron β^+. The sum of the K.E. of the particles is equal to that of the photon less 1.02 Mev.

Macroscopically, when γ-rays of intensity 'I_o' pass through a slab of material of thickness 'x' and total linear absorption coefficient 'μ', the intensity is reduced. It can be shown that the emerging radiation intensity is given by

$$I_x = I_o \, e^{-\mu x} \qquad \text{(D1)}$$

and

$$\mu = \mu_A + \mu_B + \mu_C \qquad \text{(D2)}$$

where subscripts A, B and C refer to the absorption processes above.

Fig. D.1 shows the absorption coefficients for the three processes for lead and over a wide range of γ-energies.

A reduction in intensity could well take place even without interaction with matter. This is strictly true for an uncollimated beam where the intensity is decreased in proportion to the inverse of the square of the distance from the source, S, or

$$I = \frac{K \, I_o}{S^2} \qquad \text{(D3)}$$

where I_o is the source strength and K is a proportionality constant.

This does not apply to a collimated beam, where the intensity is reduced only by interaction with matter in its path.

The γ-ray source used here is Csesium 137 (Cs^{137}). It decays into Ba^{137} by the emission of β^- (8%) or β^- followed by γ-rays (92%) as shown in Fig. D.2. Because of the high absorption cross-section for β^--rays (compared to γ-rays) in air, the radiation from the source can be considered as wholly γ-rays.

D.2 DETECTION OF RADIATION

There are various ways of detecting radiation in addition to photographic techniques. Most of these employ one of the two basic techniques discussed below.

D.2.1 INTEGRATION METHOD (Gas ionisation detectors)

When γ-rays impinge on a cylinder filled with gas, ions are produced. If an electrode is fitted at the centre, insulated from the earthed cylinder and has a +ve potential, then these ions can be collected and the small current produced is measured. By increasing the voltage at the central electrode the corresponding number of ions collected increases in a manner shown in Fig. D.3. Ionisation chambers, proportional counters and Geiger Müller counters are in this category, and differ only in the range of voltage as shown in Fig. D.3. When used for γ-ray detection and measurements, the ionisation chambers are normally filled with an inert gas at high pressures (up to 20 atm.). This is to increase the number of molecules per unit volume, and hence the sensitivity.

γ-ray absorption coefficient in lead (Ref. F5)

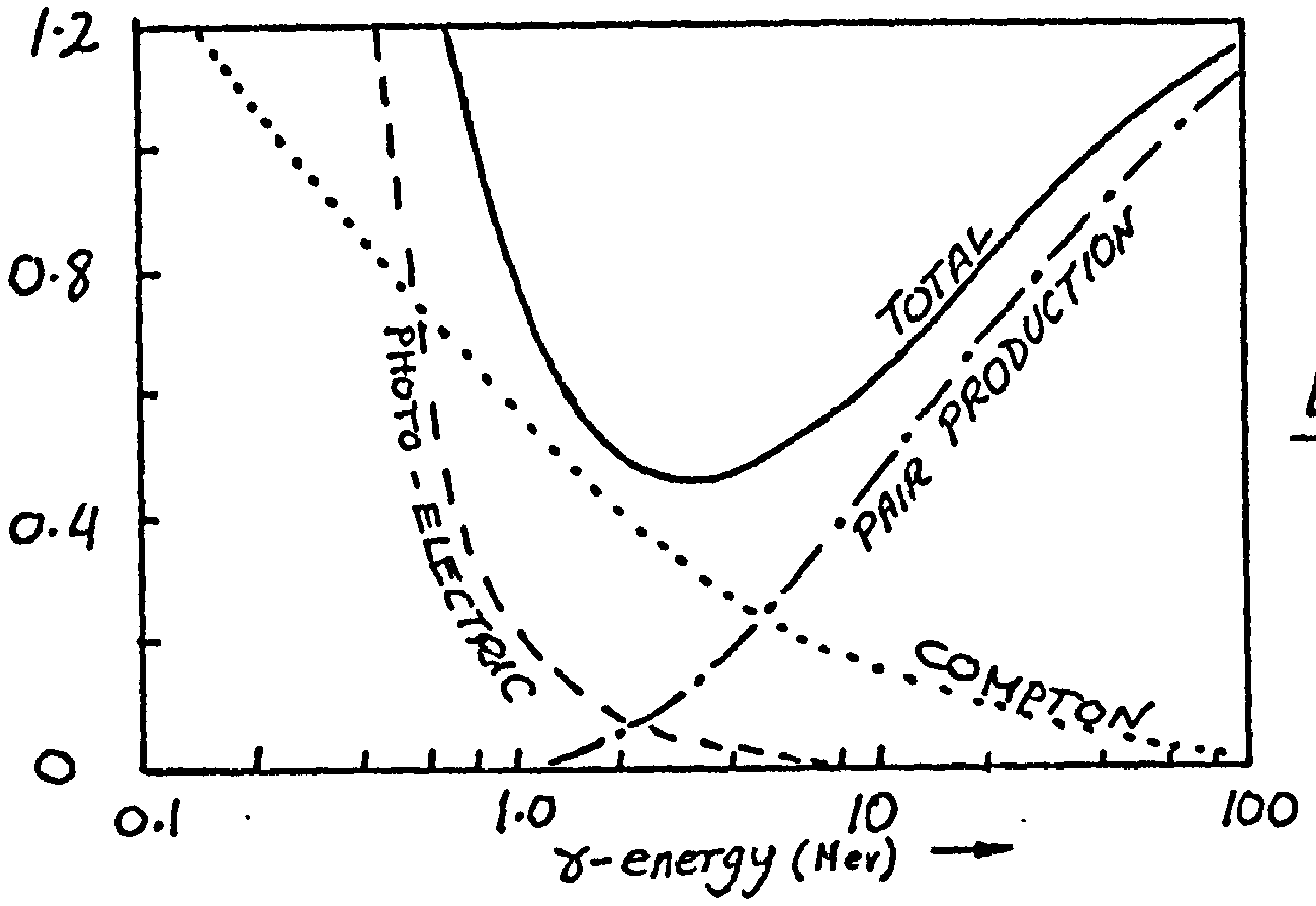
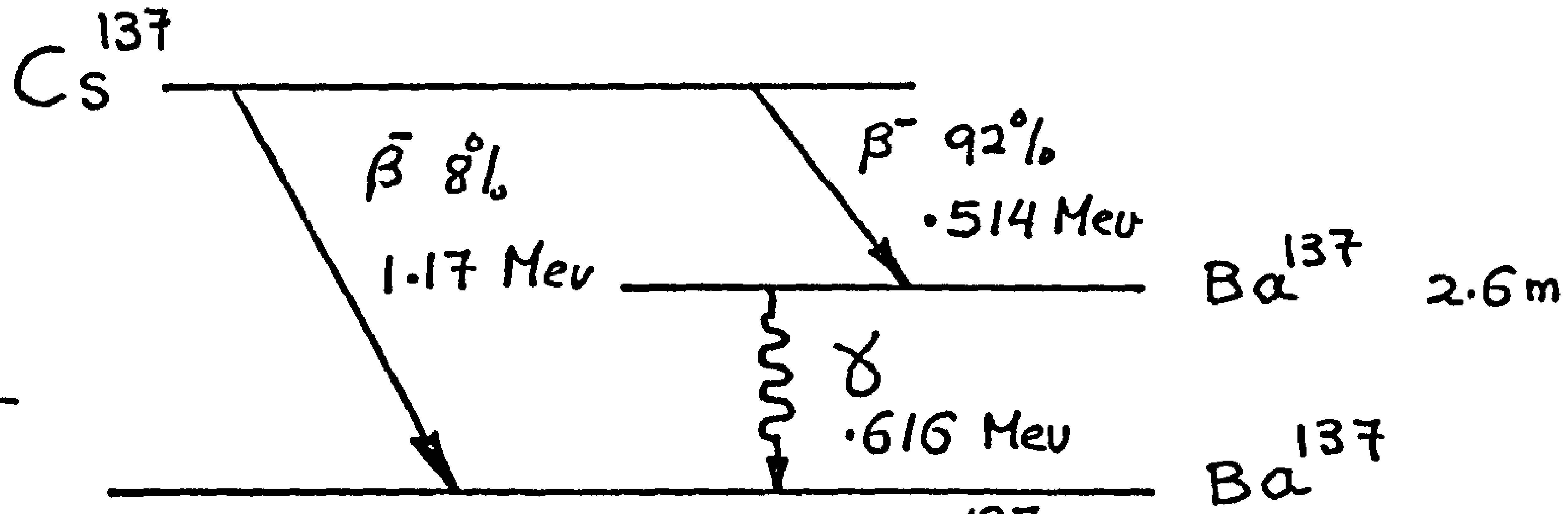


FIG. D1

FIG. D2



decay scheme of Cs^{137} (Ref. O4)

voltage-current characteristics of gas filled detectors (Ref. L9)

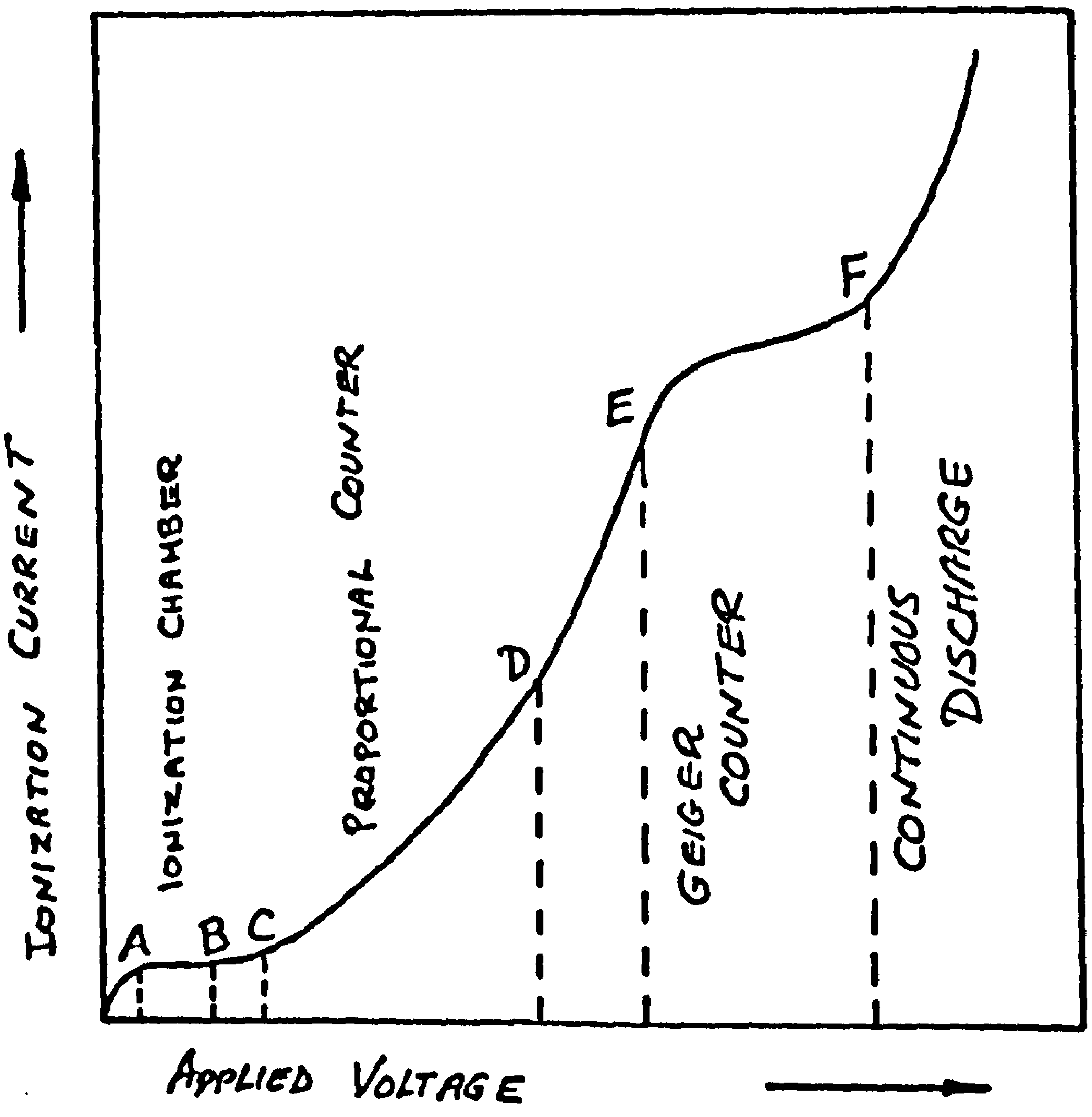


FIG. D3

D.2.2 SPECTROMETER METHOD (Scintillation detectors)

This method employs scintillation detectors which are particularly useful for γ-rays because of their high efficiency. Here the incident photons interact with the crystalline solid or liquid phosphors by any one or more of the processes mentioned earlier. The net result is the emission of secondary particles, photons, or both. Deceleration of the particles or absorption of the low energy photons (if not escaped) is effected by the atoms of the phosphors which become excited. De-excitation is fulfilled by the emission of electromagnetic radiation, mostly visible light. The light is allowed to fall on a photosensitive material where it causes the emission of one or more electrons. These are accelerated towards another electrode called 'dynode' where by collision more electrons are ejected. Up to eleven stages or more can be used with the net result that a burst of electrons is produced for every photon incident. Amplification factors of 10^5-10^9 are normally quoted in the literature. Such instruments are widely known as 'photomultiplier tubes'.

D.3 ASSOCIATED ELECTRONIC EQUIPMENT

In general, pulse counters consist of the following

(i) High Voltage Supply:

To supply the required voltage to operate the detector. Normally high quality of regulation is required.

(ii) Preamplifier:

This unit acts as an intermediate stage between the detector and other electronic equipment. It has the following characteristics:

a - High input impedance, drawing very little current from detector.

b - Low output impedance to deal with losses in long cables without serious fall in voltage (impedance matching).

c - Almost no voltage gain.

d - Constant frequency response over a wide range of frequencies.

(iii) Amplifier:

Features a high gain and linear response, i.e. output is proportional to input. The latter is important for spectrometry whereby the pulse height is used as a measure of the photon energy.

(iv) Pulse Height Analyser:

Consists mainly of two discriminators* and an anticoincidence circuit.** One discriminator is set at a voltage level 'H', the other at a voltage level

---

* Discriminator : An electronic circuit which allows only voltage signals greater than a pre-set value to pass.

**Anticoincidence circuit: An electronic circuit which requires two inputs. It produces a zero output signal if the two inputs correspond to the same event.

'H + ΔH'. 'H' is referred to as the 'Threshold' and 'ΔH' as the 'Gate width. Their main job is to allow pulses of height lying between 'H' and 'H + ΔH' to pass, hence make it easy to determine the differential pulse height spectrum. Also it can be used to isolate the required photon energy by truncating those signals which correspond to unwanted scattered low energy photon. This can be done by adjusting the levels 'H' and 'H + ΔH' to contain the required photon energy only.

(v) Data Registration:

The function of the unit is to allow the measurements of the number of pulses put out by the detecting system per unit time. It consists mainly of scalars (storage and digitised output), meter movement, chart recorder etc.

For the integrating measuring devices, on the other hand, most of what is mentioned above is required, although the actual mechanisms are different. Here the total charge collected per unit time is proportional to the rate of the incident radiation. Possible measuring techniques are

a - By measuring the rate of charge or discharge of a capacitor.

b - By measuring the voltage developed across a precision high resistance.

The matter then reduces to the measurement of very low dc-currents ($\sim 10^{-15}$ amp). The problem of dealing with dc-amplifiers and their stability has been overcome by the use of what is known as 'the vibrating reed electrometer'. Here the dc-signal is mixed with a fixed frequency ac-signal, which can be amplified using stable ac-amplifiers, then separated again and displayed on a meter movement or chart recorder.

D.4 SETTING AND CALIBRATION OF INSTRUMENTS

It is a good practise to check the following

A - The manufacturers recommended test procedure to check the instrumental parameters such as response time, calibration etc.

B - Plateau Region: Here the output of the instrument is relatively unaffected by small variations in the high tension supply voltage (Figs. D3 and D4).

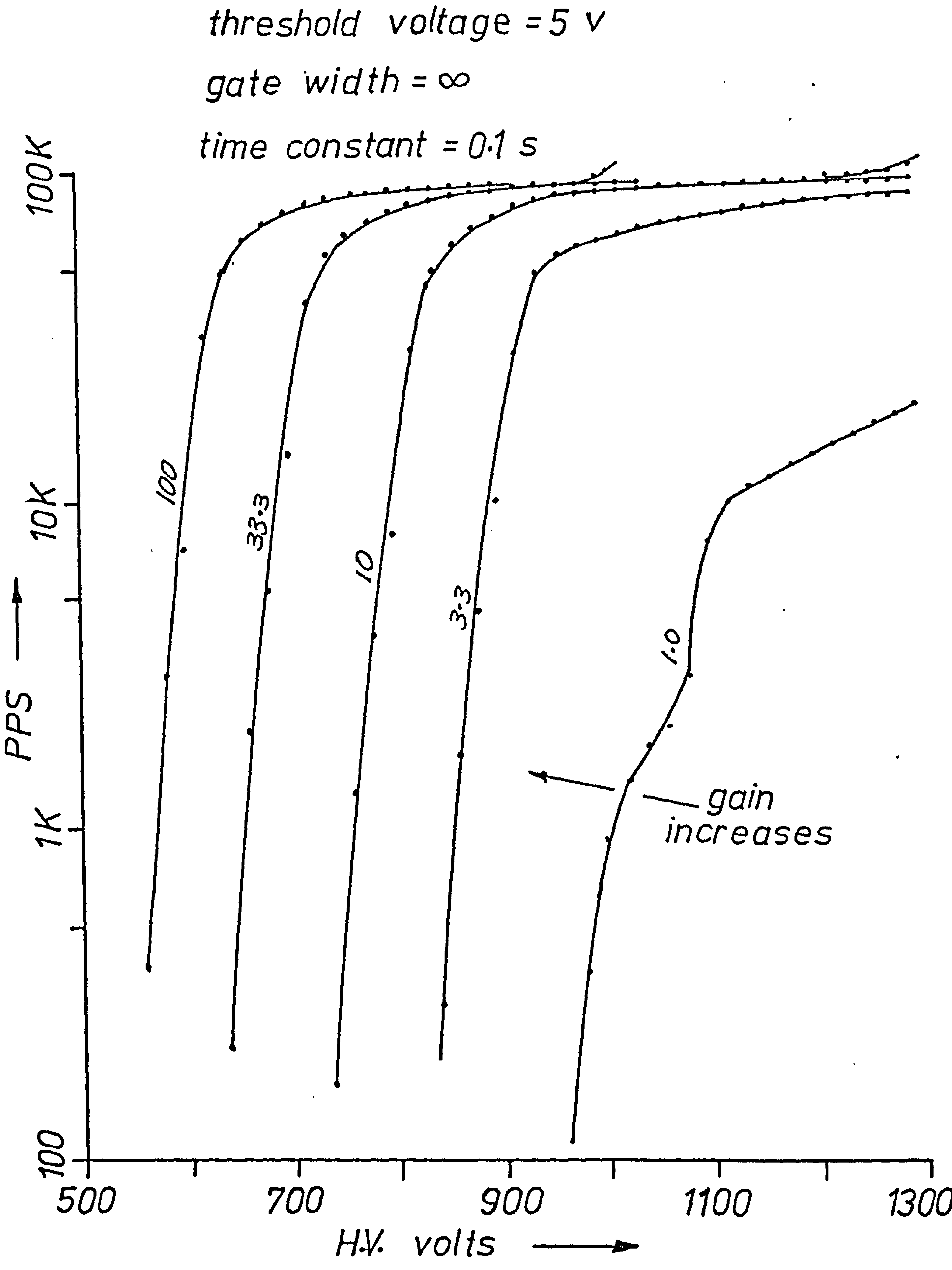
C - Linearity: If the detector is saturated then an increase in the intensity of radiation will not affect the output and hence the measured count rate.

Part 'A' above is a straightforward procedure. For part 'B', the ionisation chamber already has a plateau by definition (Fig. D.3), also such units are normally supplied with a preset power supply. For the scintillation counters, it is not so simple. Here the platea depends on different parameters as, gain, threshold, window setting and source strength (Overman and Clark, 1973). Commonly, the length of the plateau decreases and its slope increases with decreasing source strength. Hence it is important to search for the plateau in-situ, i.e. using the same source and for different gain and discriminator setting. Fig. D.4 shows the relationship between pps (pulse per sec) and the high tension voltage for a given set of instrument parameters. Several of these graphs were drawn for different thresholds. After choosing the working point, a search is made for the peak in the spectrum which corresponds to the 0.616 Mev emission of Cs^{137}. This is shown in Fig. D.5 with the instrument parameters setting being a compromise between pps at the peak ($\sim$1.12 volts threshold) and resolution. The uncertainty in the readings is greater as one moves away from the peak and is due to the random errors. Also the more absorption the γ -rays suffer, the less energy they have and the result is a shift in the peak towards a lower threshold value, as shown in Fig. D.6. As can be seen, stabilisation of the threshold voltage is also important since one is normally working along the relatively sharp edge of the spectrum (i.e. γ-spectrum).

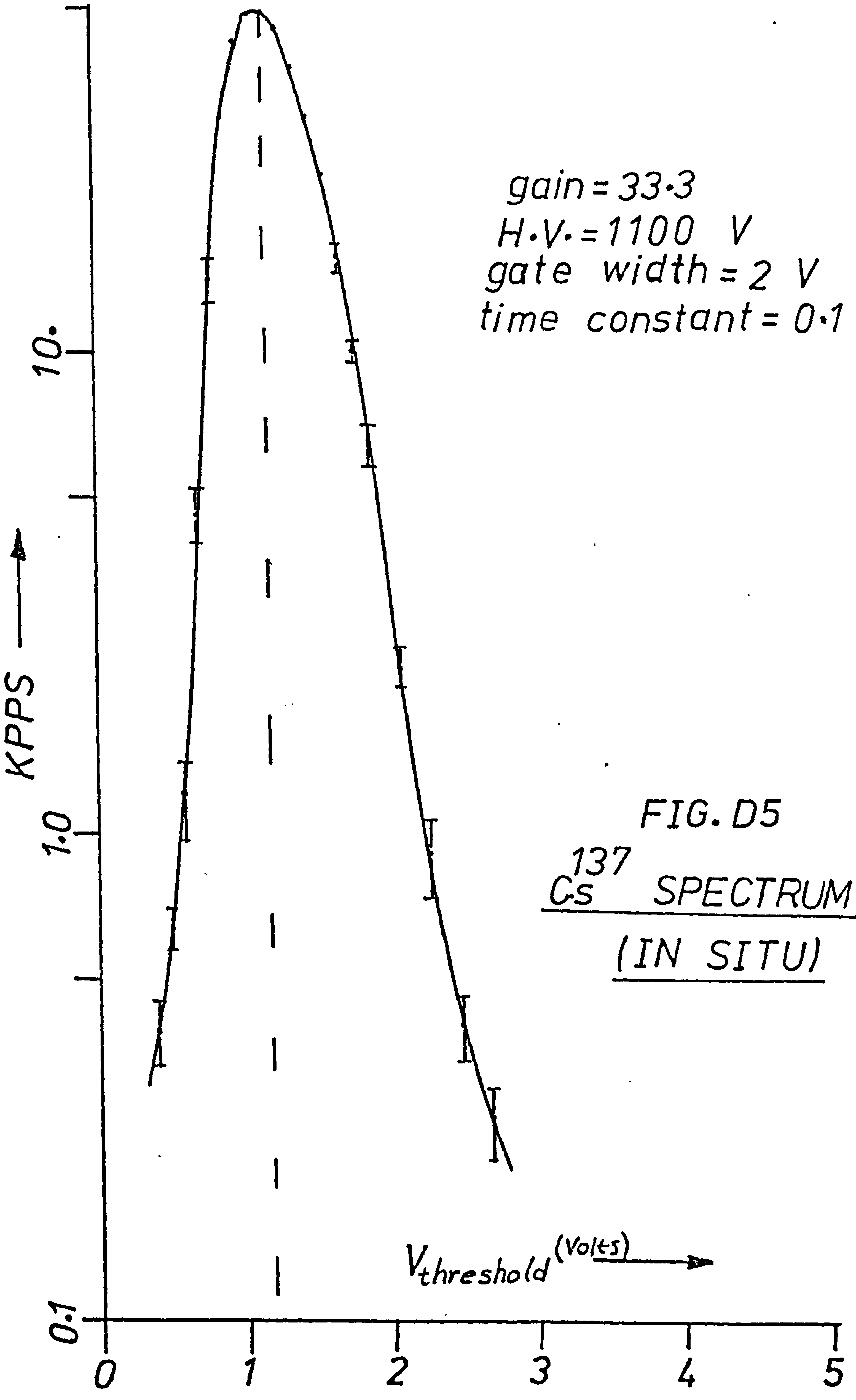
To accomplish part (C) above, a simple experiment was carried out whereby a measurement was made of the γ-ray intensity after passing through steel plates of different thicknesses. From equation (D1) above,

$$\ln(I/I_o) = -\mu x$$

Hence a plot of '$\ln(I/I_o)$' against 'x' should produce a straight line with a negative slope. Fig.D.7 shows such results for the NaI scintillation counter used



FIG·D4 DETECTOR CHARACTERISTICS

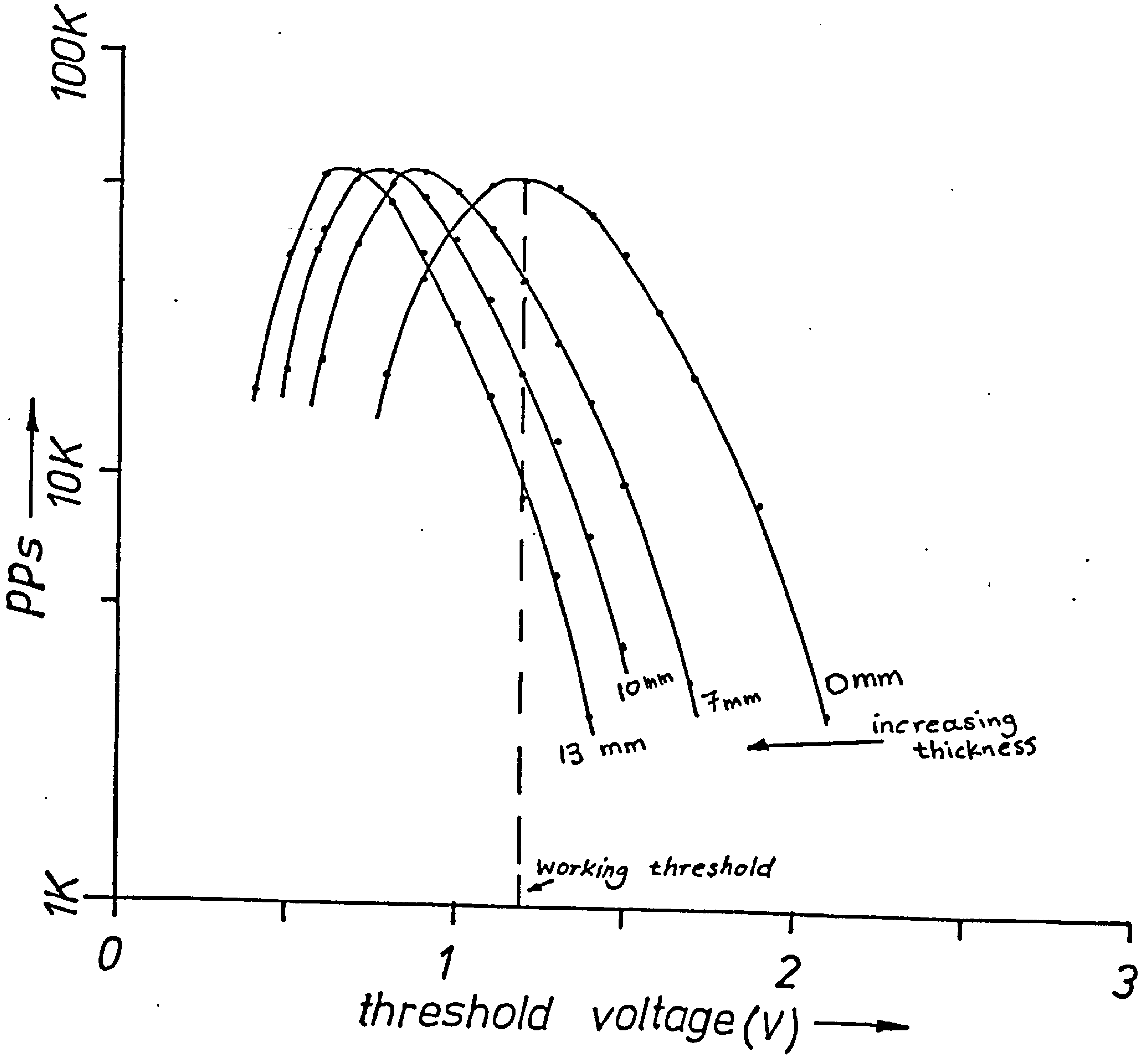


gain = 33·3
H·V· = 1100 V
gate width = 2 V
time constant = 0·1 S

FIG. D5

^{137}Cs SPECTRUM

(IN SITU)



FIG·D6 Cs^{137} SPECTRUM

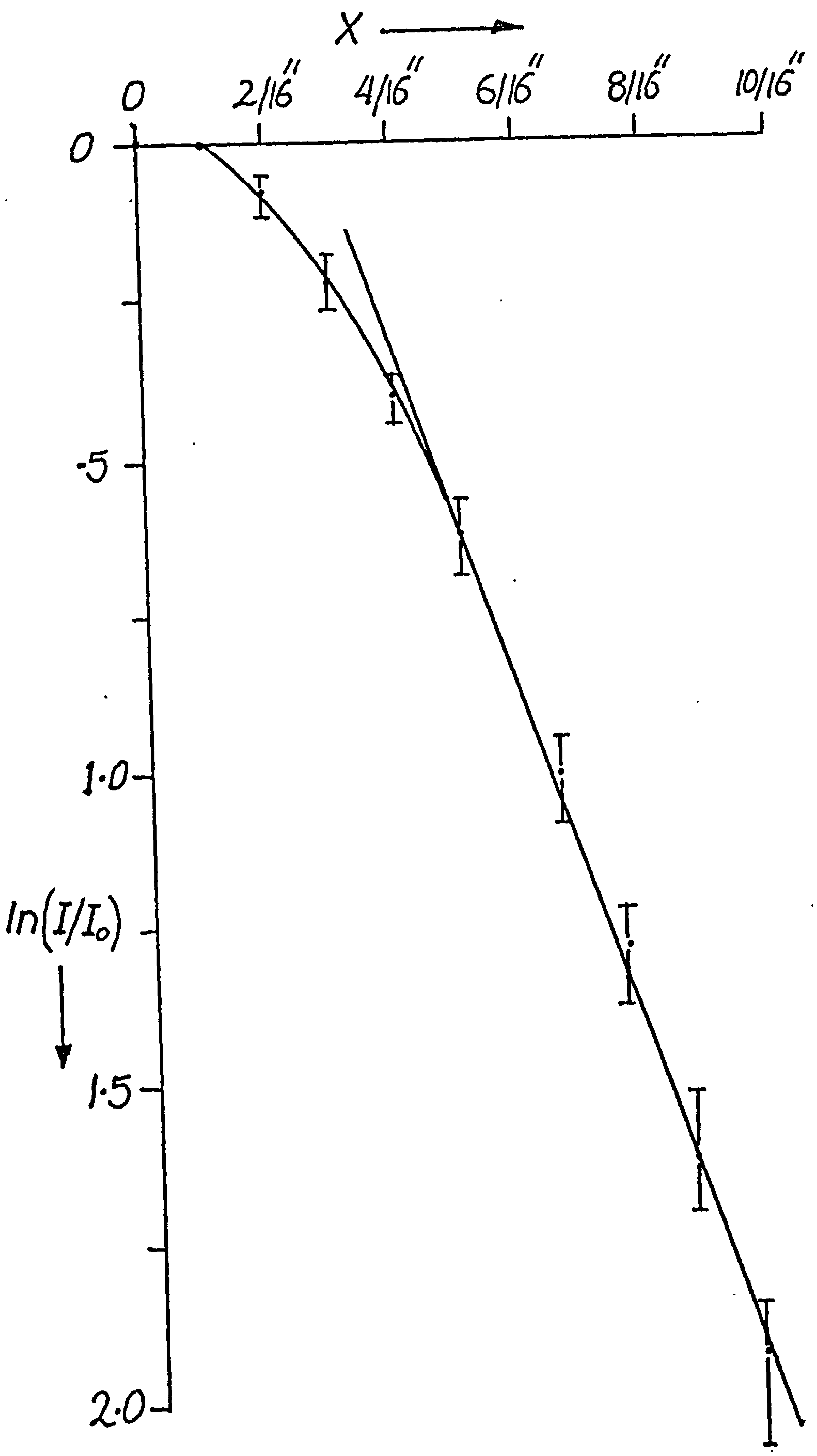


FIG. D7 DETERMINING THE SATURATION REGION OF THE DETECTOR in the void fraction fluctuation studies for the 127 mm (5") pipe. A similar graph was drawn for the 216 mm (8.5") pipe since the diameter of the γ-ray pencil beam had to be increased to cope with the increase in diameter of the pipe (and hence absorption) so as to keep the count rate relatively high for statistical accuracy. For the ionisation chamber, on the other hand, an in-situ calibration could be carried out regularly. This is explained in more detail in Appendix E.

Finally, a check on the background radiation effects was carried out to determine if these were significant. This was done with the source removed from the set up. The main effect of neglecting this is that the apparent γ-ray intensity is the sum of the actual value plus the background value. Discussion concerning such errors is presented later in Appendix E.

APPENDIX E

FURTHER DETAILS AND PRINCIPLES OF GAMMA RAY ATTENUATION METHOD

APPENDIX E FURTHER DETAILS AND PRINCIPLES OF GAMMA RAY ATTENUATION METHOD

E.1 UNCERTAINTIES IN MEASUREMENTS

The void fraction 'α' can be estimated using the appropriate measured intensities of γ-rays in terms of voltage or current output. The commonly used expression is

$$\alpha = \frac{\ln(I/I_F)}{\ln(I_G/I_F)} \tag{E1}$$

where the subscripts F and G refer to tube full of water and air (tube empty) respectively. As can be seen from equation (E1), the errors in the measurements of any of the quantities I, I_F and I_G, do not affect the accuracy of α linearly. Let the uncertainties (positive or negative) in the measurement of 'I' be 'ΔI', of 'I_F', be 'ΔI_F', and of 'I_G', be 'ΔI_G'. By applying small perturbations to I, I_F and I_G, the resultant perturbation on 'α' is '$\Delta\alpha$' and is given by

$$\Delta\alpha = \frac{\partial\alpha}{\partial I}\,\Delta I + \frac{\partial\alpha}{\partial I_F}\,\Delta I_F + \frac{\partial\alpha}{\Delta I_G}\,\Delta I_G \tag{E2}$$

By evaluating the appropriate derivatives using equation (E1), equation (E2) becomes

$$\Delta\alpha = \frac{1}{\ln(I_G/I_F)}\left[\frac{\Delta I}{I} - \frac{\Delta I_F}{I_F} + \alpha\,\frac{\Delta I_F}{I_F} - \alpha\,\frac{\Delta I_G}{I_G}\right] \tag{E3}$$

The condition of maximum (or minimum) possible error in the measurement of 'α' is

$$\frac{d(\Delta\alpha)}{d\alpha} = 0 \qquad \text{(E4a)}$$

or

$$\frac{\Delta I_F}{I_F} = \frac{\Delta I_G}{I_G} \qquad \text{(E4b)}$$

Substituting back in (E3) and dividing by 'α' to get the fractional error,

$$\frac{\Delta\alpha}{\alpha} = \frac{1}{\alpha \ln(I_G/I_F)} \left[\frac{\Delta V}{V} - \frac{\Delta V_F}{V_F}\right] \qquad \text{(E5)}$$

The maximum error occurs when 'ΔI' and ' I_F' are out of phase, i.e. 'I' is overestimated by 'ΔI' while 'I_F' is underestimated by 'ΔI_F'. If we further assume that the fractional errors (e.g. $\Delta I/I$) are equal, or

$$\frac{\Delta I}{I} = \frac{\Delta I_F}{I_F} = \frac{\Delta I_G}{I_G} = K \qquad \text{(E6)}$$

Then the maximum percentage error is

$$\left(\frac{\Delta\alpha}{\alpha}\right)_{max.}\% = \frac{K}{(\frac{\alpha}{2})\ \ln(I_G/I_F)} \times 100 \qquad \text{(E7)}$$

The above result is quoted in Hooker and Pooper (H18). Equation (E7) can be written as

$$\left[\left(\frac{\Delta\alpha}{\alpha}\right)_{max.}\%\right] \ln\ (I_G/I_F) = \frac{2K}{\alpha} \times 100$$

This is shown in Fig. E.1a for different values of K.

The minimum error of course occurs when 'ΔI' and 'ΔI_F' are in phase, and by assuming equation (E6) to be true, we get

$$\left(\frac{\Delta\alpha}{\alpha}\right)_{min}\% = 0 \qquad \text{(E8)}$$

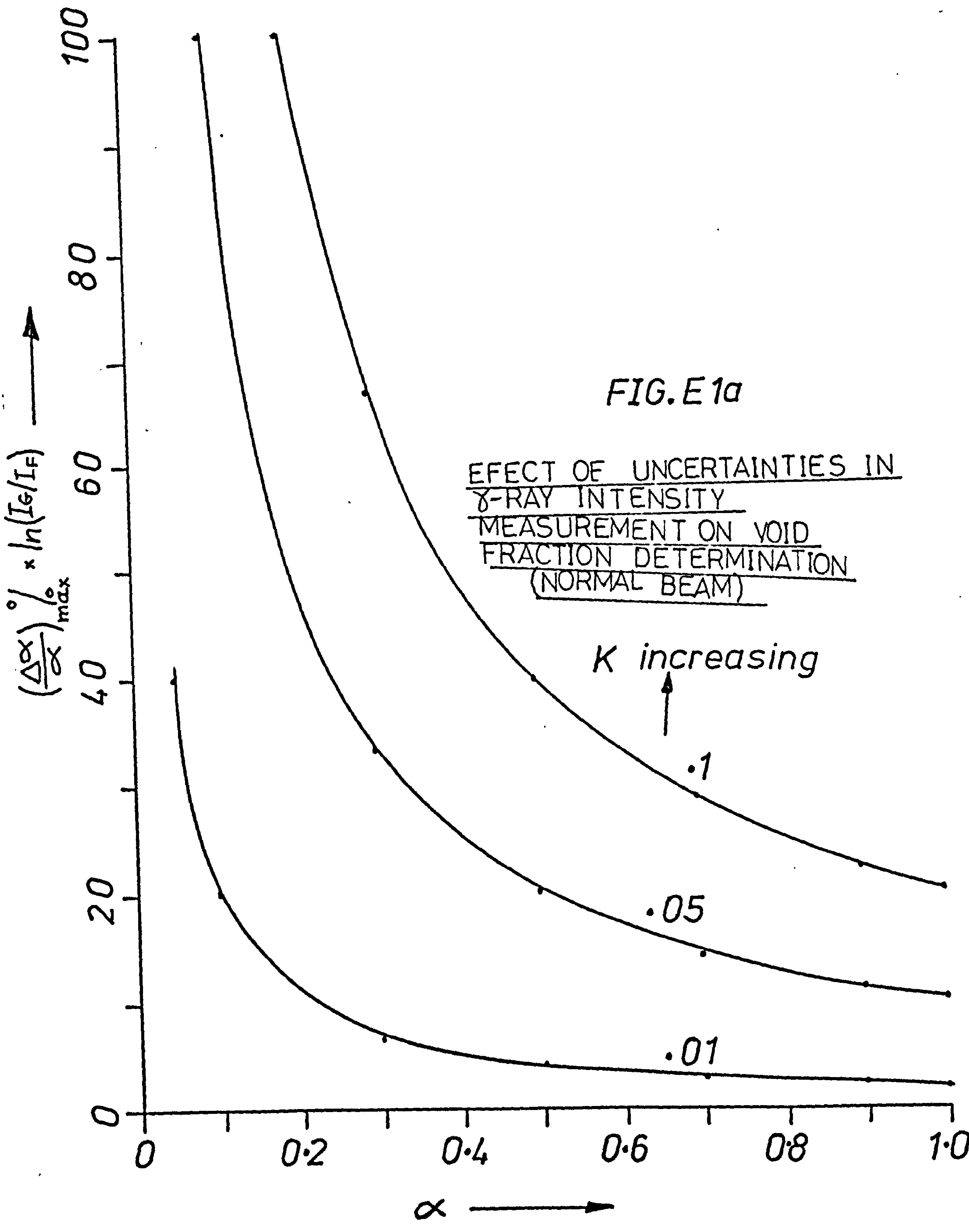


FIG. E1a

EFECT OF UNCERTAINTIES IN γ-RAY INTENSITY MEASUREMENT ON VOID FRACTION DETERMINATION (NORMAL BEAM)

Another void fraction relationship which is recommended when the γ-ray beam is parallel to the plane of phase separation is,

$$\alpha = \frac{I - I_F}{I_G - I_F} \qquad \text{(E9)}$$

And a similar procedure gives

$$\left(\frac{\Delta\alpha}{\alpha}\right) = \frac{\Delta I - \Delta I_F}{\alpha\,(I_G - I_F)} \qquad \text{(E10)}$$

From equation (E6) with ' I' and ' I_F' in phase, then

$$\left(\frac{\Delta\alpha}{\alpha}\right)_{min}\% = K \times 100 \qquad \text{(E11)}$$

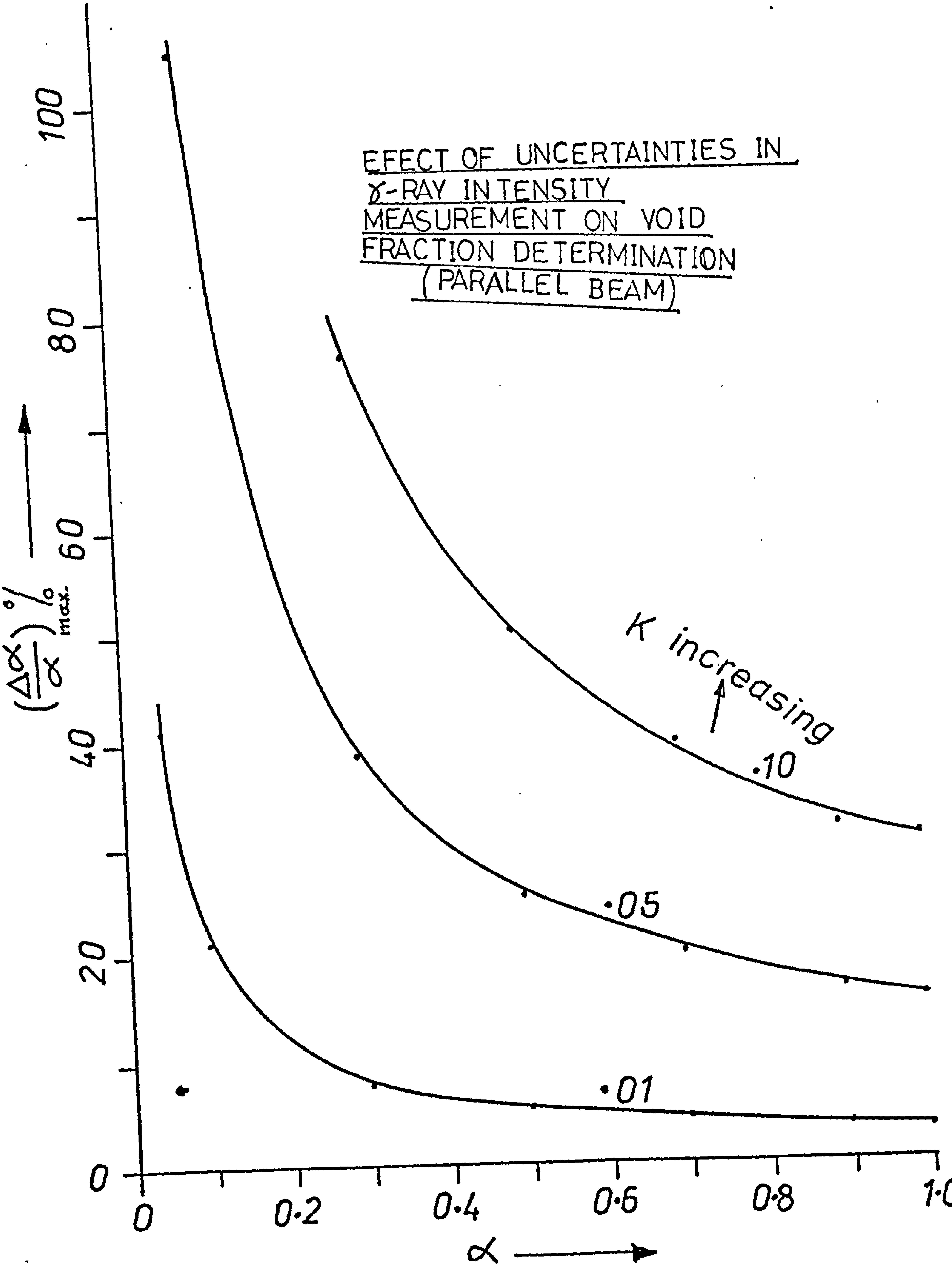
If 'ΔI' and 'ΔI_F' are out of phase, then equation (E6) gives

$$\left(\frac{\Delta\alpha}{\alpha}\right)_{max}\% = K\left(\frac{1 + I_F/I}{1 - I_F/I}\right) \qquad \text{(E12)}$$

The above equation can be written with the help of equation (E9) in a more convenient form,

$$\left(\frac{\Delta\alpha}{\alpha}\right)_{max}\% = K \; \frac{2 + \alpha\left(\frac{I_G}{I_F} - 1\right)}{\alpha\left(\frac{I_G}{I_F} - 1\right)} \times 100$$

and the results are shown in Fig.E1b for different values of K.



EFECT OF UNCERTAINTIES IN γ-RAY INTENSITY MEASUREMENT ON VOID FRACTION DETERMINATION (PARALLEL BEAM)

FIG. E 1b

E.2 DERIVATION OF VOID FRACTION FORMULAE FOR RECTANGULAR CHANNELS

CASE 1: RADIATION NORMAL TO PLANE OF PHASE SEPARATION (see Fig. E.2)

Referring to Fig. E.2 where a monochromatic radiation is allowed to penetrate a liquid of path length 'x_F' and a gas of path length 'x_G' which constitutes a certain phase distribution in a rectangular channel of breadth 'W', thickness 'L' and unit length.

The emerging beam intensity per unit area along the direction of the incident beam is I_M and is given by

$$I_M = I_o\, e^{-\mu_F x_F - \mu_G x_G - 2\delta\mu} \qquad \text{(E13)}$$

where I_o is the intensity of incident radiation per unit area.

μ, μ_F and μ_G are the linear absorption coefficients of wall material, liquid and gas respectively,

and

δ is the wall thickness.

If the channel is full of liquid, the intensity of the emerging radiation is given by

$$I_F = I_o\, e^{-\mu_F L - 2\delta\mu} \qquad \text{(E14)}$$

Also, for tube full of gas,

$$I_G = I_o\, e^{-\mu_G L - 2\delta\mu} \qquad \text{(E15)}$$

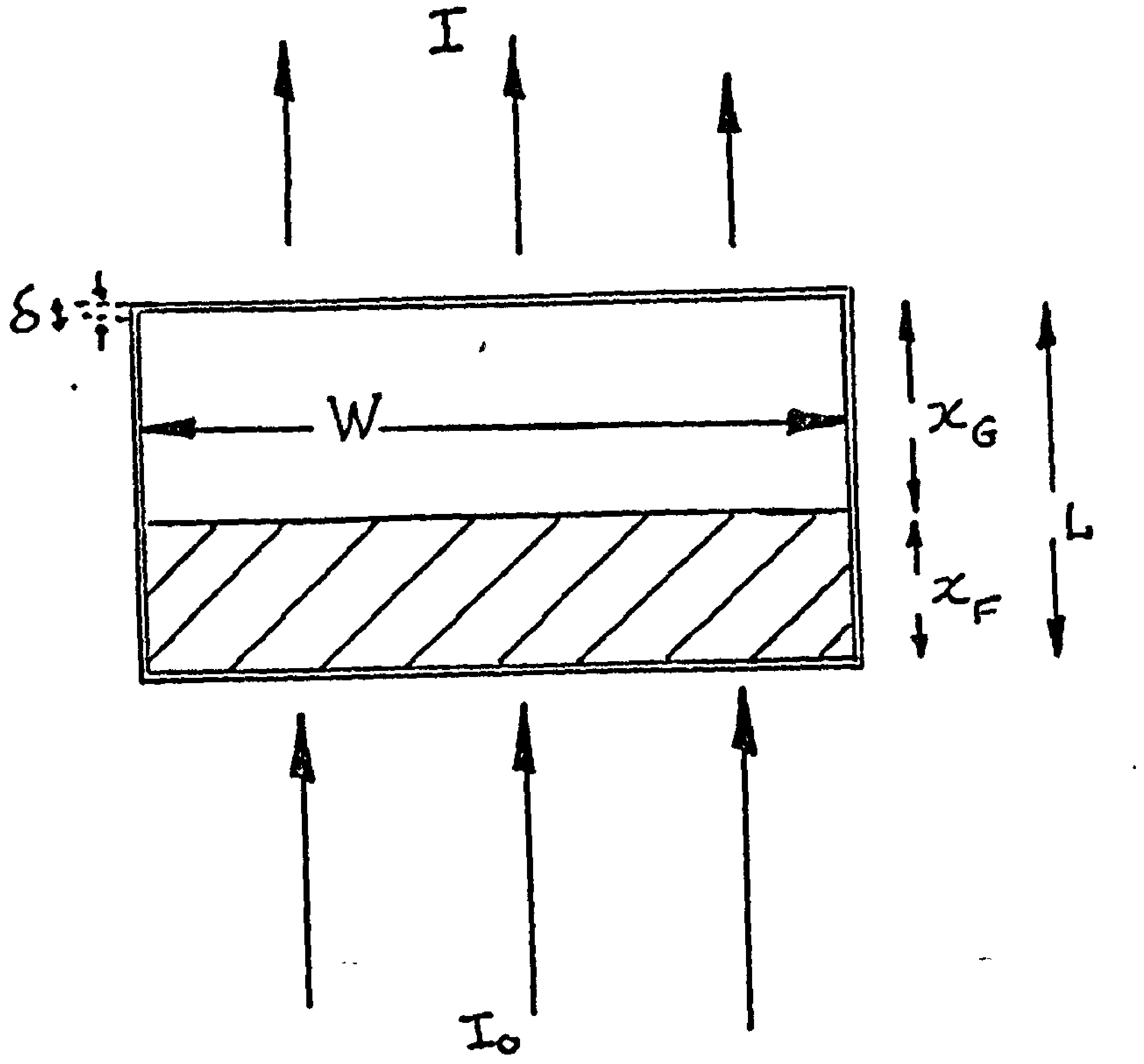


FIG. E2 γ - BEAM $\perp$ TO PLANE OF PHASE SEPARATION

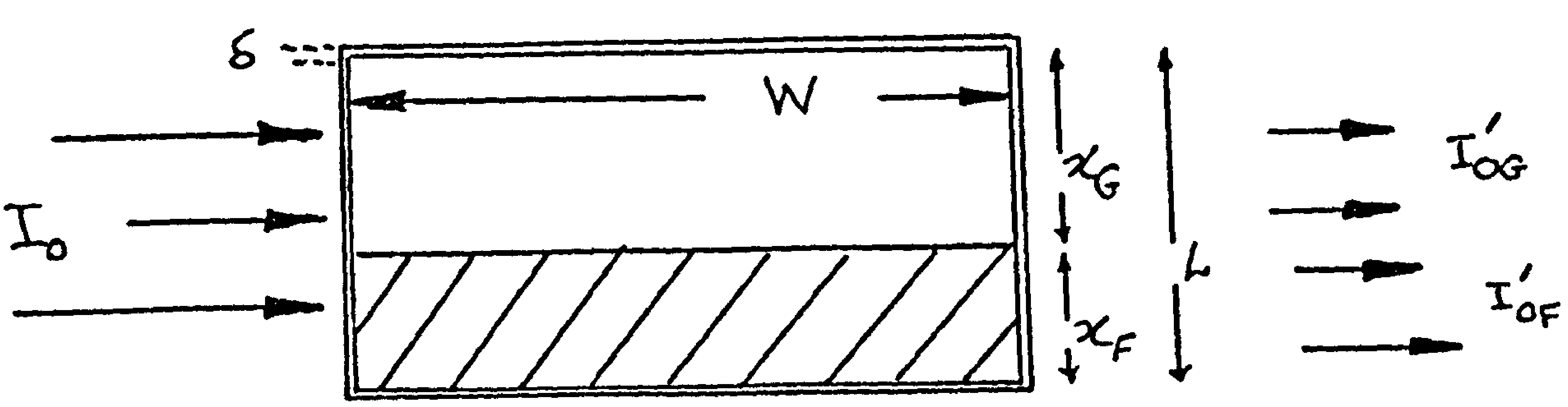


FIG. E3 γ - BEAM // TO PLANE OF PHASE SEPARATION where

$$L = x_F + x_G \tag{E16}$$

From equations (E13), (E14) and (E15)

$$-\mu_F x_F - \mu_G x_G - 2\delta\mu = \ln (I_M/I_o) \tag{E17}$$

$$-\mu_F L - 2\delta\mu = \ln(I_F/I_o) \tag{E18}$$

and

$$-\mu_G L - 2\delta\mu = \ln(I_G/I_o) \tag{E19}$$

Subtracting equation (E18) from (E17)

$$-\mu_F x_F - \mu_G x_G - 2\delta\mu + \mu_F L + 2\delta\mu = \ln(I_M/I_F)$$

or

$$x_G(\mu_F - \mu_G) = \ln(I_M/I_F) \tag{E20}$$

Subtracting equation (E18) from (E19)

$$-\mu_G L - 2\delta\mu + \mu_F L + 2\delta\mu = \ln(I_G/I_F)$$

or

$$L(\mu_F - \mu_G) = \ln(I_G/I_F) \tag{E21}$$

Hence from equations (E20) and (E21), the void fraction is given by

$$\alpha = \frac{x_G}{L} = \frac{\ln (I_M/I_F)}{\ln (I_G/I_F)} \tag{E22}$$

CASE 2: RADIATION PARALLEL TO PLANE OF PHASE SEPARATION (see Fig. E.3)

Referring to Fig. E.3 where the same monochromatic radiation is allowed to pass horizontally through the same channel with the same phase distribution, if the total intensity of the incident radiation per unit area is I_o, then the fraction attenuated by liquid is,

$$\frac{x_F}{L} I_o = I_{oF} \tag{E23}$$

and by gas

$$\frac{x_G}{L} I_o = I_{oG} \tag{E24}$$

The intensities of the emerging radiation are given by

$$\begin{aligned} I'_{oF} &= I_{oF}\, e^{-\mu_F W - 2\delta\mu} \qquad \text{(E25)} \\ &= \left(\frac{x_F}{L}\right) I_o\, e^{-\mu_F W - 2\delta\mu} \end{aligned}$$

and

$$\begin{aligned} I'_{oG} &= I_{oG}\, e^{-\mu_G W - 2\delta\mu} \\ &= \left(\frac{x_G}{L}\right) I_o\, e^{-\mu_G W - 2\delta\mu} \qquad \text{(E26)} \end{aligned}$$

such that the total intensity of the emerging radiation I_M is

$$\begin{aligned} I_M &= I'_{oF} + I'_{oG} \\ &= \left(\frac{x_F}{L}\right) I_o\, e^{-\mu_F W-2\delta\mu} + \left(\frac{x_G}{L}\right) I_o\, e^{-\mu_G W-2\delta\mu} \end{aligned} \tag{E27}$$

If the channel is full of liquid, then the corresponding intensity of the emerging radiation is,

$$I_F = I_o\, e^{-\mu_F W-2\delta\mu} \tag{E28}$$

and for the channel full of gas,

$$I_G = I_o\, e^{-\mu_G W-2\delta\mu} \tag{E29}$$

Substituting in (E27) for the experimental terms from (E28) and (E29)

$$I_M = (\frac{x_F}{L})\ I_o\ (\frac{I_F}{I_o}) + (\frac{x_G}{L})\ I_o\ (\frac{I_G}{I_o})$$

and since

$$\alpha = \frac{x_G}{L} \text{ and } \quad 1 - \alpha = \frac{x_F}{L} \tag{E30}$$

then

$$I_M - I_F = \alpha(I_G - I_F)$$

or

$$\alpha = \frac{I_M - I_F}{I_G - I_F} \tag{E31}$$

Equations (E22) and (E31) were derived in Appendix 1 of ref. (S20), also in Richardson (R1).

E.3 THE EFFECT OF UNCORRECTED ZERO READING ON THE ACCURACY OF MEASUREMENTS

One of the factors which can affect the accuracy of the γ-ray attenuation technique is the presence of a zero error reading which has not been corrected for. Such zero errors may arise due to:

(i) The presence of a voltage or current output due to either the readout unit or the sensing device (e.g. photomultiplier tubes) at a time where the γ-ray intensity is supposed to be zero. This may be due to a zero drift in the electronic circuit or in case of photomultiplier tube, the presence of what is known as 'dark current'.

This current is due to thermally generated electrons and other factors such as field emission, etc. (Birks, B15). For this reason it is very important to build a cooling chamber around the P.M. tube, especially when working in a high temperature environments or when applying comparatively high tension to the dynodes, i.e. operating the tube near its maximum permissible voltage, normally to get higher gain.

(ii) The presence of appreciable background radiation due to either the presence of radiation sources in the neighbourhood or to bad shielding of the detecting unit against scattered radiation. This can be reduced by using pulse height analysers with the discriminator and gate set to enclose the peak in the spectrum of the source.

(iii) Radiation not passing through the two phase mixture and hence not attenuated, but still impinging on the detector, and hence counted. This can be overcome by careful collimation of the gamma ray beam.

Let subscripts 'A' and 'B' refer to 'Apparent' and 'Background' respectively. Thus for the actual intensities,

$$I_G = I_{GA} - I_B$$

$$I_F = I_{FA} - I_B \qquad \text{(E32)}$$

and

$$I_M = I_{MA} - I_B$$

where subscripts G, F and M refer to tube full of gas, full of liquid and full of the two phase mixture, respectively.

The apparent void fraction α_A is defined as,

$$\alpha_A = \frac{\ln (I_{MA}/I_{FA})}{\ln (I_{GA}/I_{FA})} \qquad \text{(E33)}$$

The actual void fraction α is

$$\alpha = \frac{\ln (I_M/I_F)}{\ln (I_G/I_F)} \qquad \text{(E34)}$$

or

$$\alpha = \frac{\ln (\frac{I_{MA}}{I_B} - 1)/(\frac{I_{FA}}{I_B} - 1)}{\ln (\frac{I_{GA}}{I_B} - 1)/(\frac{I_{FA}}{I_B} - 1)} \qquad \text{(E35)}$$

For simplicity, write the apparent intensities in terms of the apparent tube full of liquid value, 'I_{FA}',

$$I_{GA} = a\, I_{FA} \qquad a \gg 1$$

$$I_{MA} = b\, I_{FA} \qquad 1 \leqslant b \leqslant a \qquad \text{(E36)}$$

and

$$I_B = c\, I_{FA} \qquad 0 \leqslant c \leqslant 1$$

Then from (E33) and (E36)

$$\alpha_A = \frac{\ln(b)}{\ln(a)} \qquad \text{(E37)}$$

and from (E35) and (E36)

$$\alpha = \frac{\ln\left[(b-c)/(1-c)\right]}{\ln\left[(a-c)/(1-c)\right]} \qquad \text{(E38)}$$

The percentage error is by definition,

$$\frac{\Delta\alpha}{\alpha}\,\% = \frac{\alpha_A - \alpha}{\alpha} \times 150 \qquad \text{(E39)}$$

Figs. E.4 and E.5 show some of the results for $a = 10$ and over a range of c values.

When the gamma ray beam is parallel to the plane of phase separation, the recommended void fraction relation is

$$\alpha = \frac{I_M - I_F}{I_G - I_F} \qquad \text{(E40)}$$

Here, because of the linear relationship between 'α' and the measured intensities 'I_M', 'I_F' and 'I_G', the zero errors cancel out and hence

$$\alpha_A = \alpha \qquad \text{(E41)}$$

E.4 THE EFFECT OF AVERAGING INTENSITY RATIO RATHER THAN THE 'LOG' OF THE INTENSITY RATIO ON THE ACCURACY OF VOID FRACTION MEASUREMENTS

When a γ -radiation passes through a two phase mixture, it will suffer a reduction in intensity which is normally a function of time. Consider the arrangement shown in Fig. E.6 where, by measuring the intensity through a similar tube full of liquid using the same source, one can compensate for any variations in the

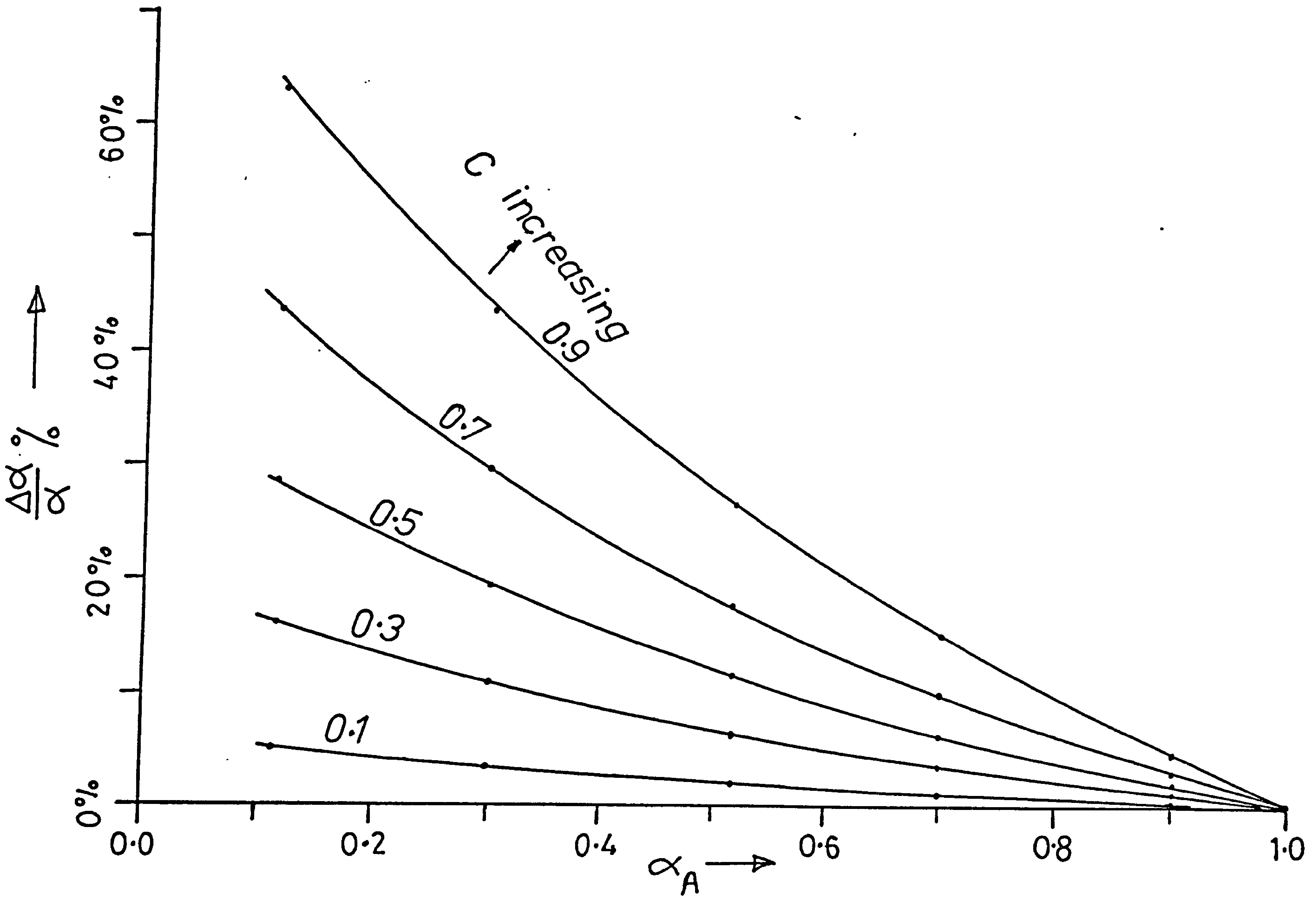


FIG. E4 EFECT OF UNCORRECTED ZERO READING ON THE ACCURACY OF VOID FRACTION MEASUREMENT (NORMAL BEAM)

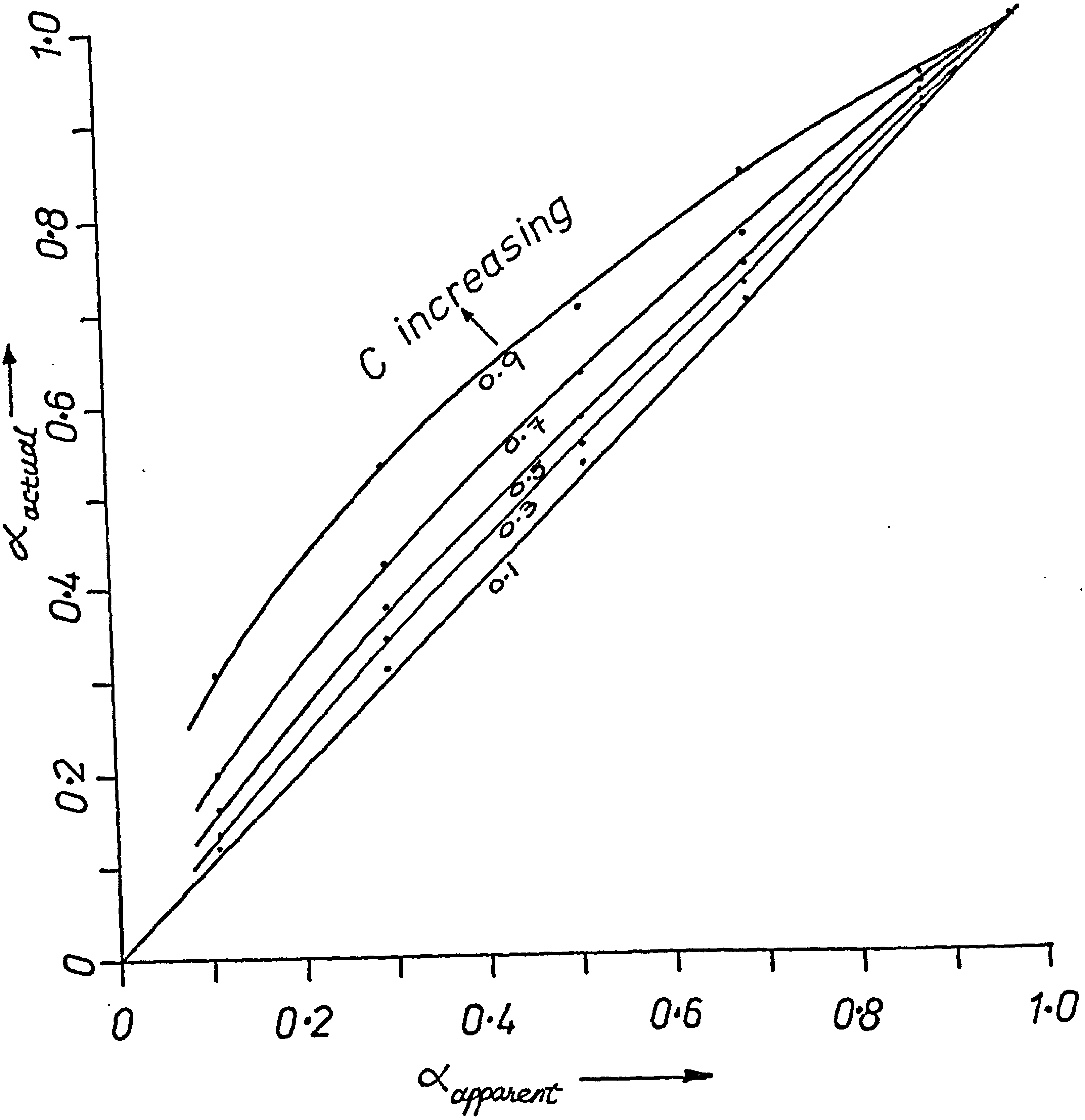


FIG. E5 EFECT OF UNCORRECTED ZERO READING ON THE ACCURACY OF VOID FRACTION MEASUREMENT (NORMAL BEAM)

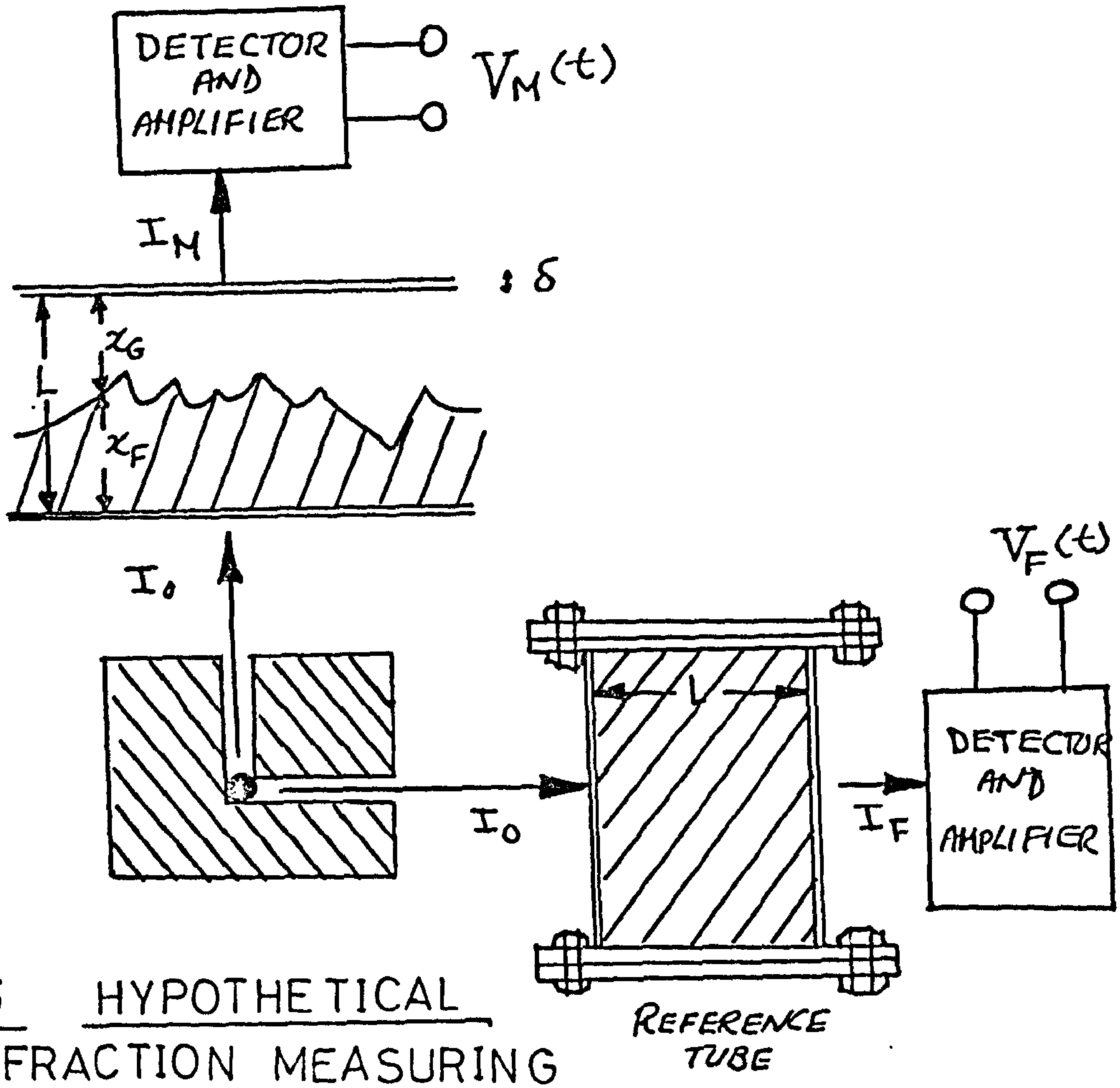


FIG. E6 HYPOTHETICAL VOID FRACTION MEASURING UNIT

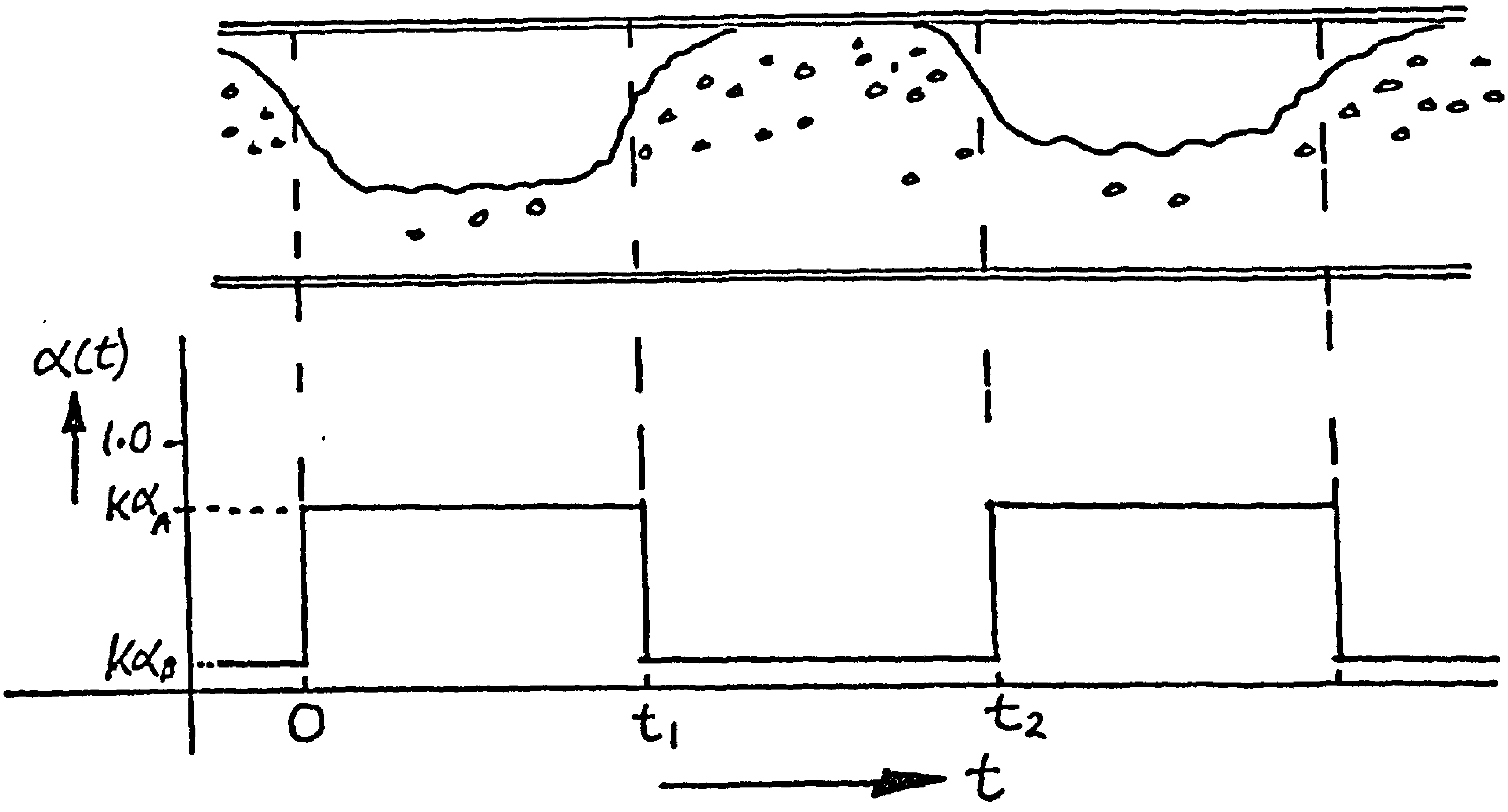


FIG. E7 SIMULATION OF VOID FRACTION IN SLUG FLOW incident intensity 'I_o' due to random processes (in case of γ-rays) or noise (in case of x-rays). In fact such an arrangement was employed by Smith (S18) in his fast response multi-beam x-ray unit used to identify phase distributions during steam-water blowdowns. In Fig. E.6 the two measuring devices must be identical and standardised and their response function constant over the range of intensities measured. Under such conditions the instantaneous output corresponding to 'I_M' is given by

$$\begin{aligned} V_M(t) &= \epsilon \; R \; I_o \, e^{-\mu_F x_F(t) - \mu_G x_G(t) - 2\delta\mu} \\ &= \epsilon \; R \; I_M(t) \qquad \text{(E42)} \end{aligned}$$

where

δ = tube wall thickness

μ, μ_F, μ_G = linear absorption coefficients of tube material, liquid and gas respectively

ϵ = detection efficiency

R = instrument response function.

Remembering that,

$$x_F(t) = \sum_i x_{iF}(t) \qquad \text{(E43)}$$

$$x_G(t) = \sum_i x_{iG}(t)$$

and

$$\alpha(t) = \frac{x_G(t)}{L} \qquad \text{(E44)}$$

where $\alpha(t)$ is the 'instantaneous void fraction' which exists in the pipe at time t, and L is the total two phase mixture path,

$$\text{i.e.} \quad L = x_F(t) + x_G(t) \tag{E45}$$

Similarly for the tube full of liquid and gas respectively,

$$V_F(t) = \epsilon R \; I_F(t) = \epsilon R \; I_o \; e^{-\mu_F L - 2\,\delta\mu} \tag{E46}$$

and

$$V_G(t) = \epsilon R \; I_G(t) = \epsilon R \; I_o \; e^{-\mu_G L - 2\,\delta\mu} \tag{E47}$$

Defining a quantity R(t) as

$$R(t) = \frac{V_M(t)}{V_F(t)} = \frac{I_M(t)}{I_F(t)}$$

$$= e^{-\mu_F x_F(t) - \mu_G x_G(t) + \mu_F L}$$

and substituting for 'L' gives,

$$\frac{V_M(t)}{V_F(t)} = e^{(\mu_F - \mu_G) x_G(t)}$$

and by using equation (E44),

$$R(t) = \frac{V_M(t)}{V_F(t)} = e^{L(\mu_F - \mu_G)\,\alpha(t)} \tag{E48}$$

The term R(t) can be thought of physically as the transmittance of the mixture relative to that of liquid. From equation (E48), the instantaneous void fraction $\alpha(t)$ is

$$\alpha(t) = \frac{1}{L(\mu_F - \mu_G)} \left[\ln \left(\frac{V_M(t)}{V_F(t)} \right) \right]$$

$$= K \ln \left(\frac{V_M(t)}{V_F(t)} \right) \tag{E49}$$

where $K = \frac{1}{L(\mu_F - \mu_G)}$ = constant

Before proceeding further, let us define another quantity W(t) as

$$W(t) = \frac{V_G(t)}{V_F(t)} = \frac{I_G(t)}{I_F(t)} = e^{-\mu_G L + \mu_F L}$$

or

$$W(t) = e^{L(\mu_F - \mu_G)} \qquad \text{(E50)}$$

In physical terms, W(t) is the maximum value the transmittance R(t) can take. From equation (E50),

$$(\mu_F - \mu_G)L = \ln W(t) = \ln \frac{V_G(t)}{V_F(t)} = \frac{1}{K} \qquad \text{(E51)}$$

and the instantaneous void fraction can be written in the more familiar form, (from equation E49),

$$\alpha(t) = \frac{\ln\left(\frac{V_M(t)}{V_F(t)}\right)}{\ln\left(\frac{V_G(t)}{V_F(t)}\right)} \qquad \text{(E52)}$$

The average void fraction over the interval 'O-T' is by definition,

$$\bar{\alpha} = \frac{1}{T}\int_0^T \alpha(t)\,dt \qquad \text{(E53)}$$

Using equation (E49) gives,

$$\bar{\alpha} = \frac{K}{T}\int_0^T \ln\left(\frac{V_M(t)}{V_F(t)}\right)\,dt \qquad \text{(E54)}$$

Equation (E54) can also be written as,

$$\text{mean void fraction} = \bar{\alpha} = K \overline{\left[\ln \frac{V_M(t)}{V_F(t)}\right]} \qquad \text{(E55)}$$

where the bar represents an average quantity.

It is fairly common practice in void fraction measurement not to average the bracketed term in equation (E55), but rather to first average the quantity '$V_M(t)/V_F(t)$' and then obtain the void fraction using equation (E49). Mathematically, this means

$$\bar{\alpha} = K \ln \overline{\left[\frac{V_M(t)}{V_F(t)}\right]} \qquad \text{(E56)}$$

and as can be seen, equations (E55) and (E56) are entirely different.

To obtain a feeling for the results, consider for example the case of slug flow in a horizontal tube (the same applies for a vertical tube). Fig. E.7 shows the slug and the corresponding approximation to the expected void fraction at that instant of time. For convenience let the void fraction be expressed in the form

$$\begin{aligned} \alpha(t) &= K\,\alpha_A & 0 \leqslant t \leqslant t_1 \\ \alpha(t) &= K\,\alpha_B & t_1 \leqslant t \leqslant t_2. \end{aligned} \qquad \text{(E57)}$$

where 'K' is as defined earlier.

By definition, the average void fraction over the interval '0-t_2' follows from equation (E53), or

$$\bar{\alpha} = \frac{1}{t_2} \int_0^{t_2} \alpha(t)\; dt$$

$$= \frac{1}{t_2} \left[\int_0^{t_2} K \;_{A} dt + \int_{t_1}^{t_2} K\alpha_B \; dt \right]$$

$$\therefore \; \bar{\alpha} = \frac{t_1}{t_2} K\alpha_A + (1 - \frac{t_1}{t_2})\; K\alpha_B \qquad \text{(E58)}$$

The correct experimental average follows from equation (E55), as

$$\bar{\alpha} = \frac{1}{t_2} \int_0^{t_2} K \ln \frac{V_M(t)}{V_F(t)} \; dt$$

using equation (E48),

$$\bar{\alpha} = \frac{K}{t_2} \int_0^{t_2} L(\mu_F - \mu_G)\; \alpha(t)\; dt$$

From equation (E51)

$$\bar{\alpha} = \frac{1}{t_2} \int_0^{t_1} K\alpha_A \; dt + \int_{t_1}^{t_2} K\alpha_B \; dt \qquad \text{(E59)}$$

which is identical to equation (E58). This is not surprising because equation (E55) was derived through equation (E53). However the procedure suggested by equation (E56), using equation (E48) gives,

$$\overline{(\frac{V_M(t)}{V_F(t)})} = \frac{1}{t_2} \int_0^{t_2} e^{\frac{\alpha(t)}{K}} \quad dt$$

$$= \frac{1}{t_2} \int_0^{t_1} e^{\alpha_A} \, dt + \int_{t_1}^{t_2} e^{\alpha_B} \, dt$$

$$\therefore \frac{V_M(t)}{V_F(t)} = \frac{t_1}{t_2} e^{\alpha_A} + (1 - \frac{t_1}{t_2}) e^{\alpha_B}$$

and the void fraction follows from equation (E56), as

$$\bar{\alpha} = K \ln \overline{(\frac{V_M(t)}{V_F(t)})}$$

$$\therefore \bar{\alpha} = K \ln \left[\frac{t_1}{t_2} e^{\alpha_A} + (1 - \frac{t_1}{t_2}) e^{\alpha_B}\right] \qquad \text{(E60)}$$

which is different from equation (E59) and (E58).

Consider the following example:

Water: $(\mu_F)_{mass} = 0.086 \frac{gm}{cm^2}$ $\qquad \rho_F = 1 \frac{gm}{cm^3}$

Air: $(\mu_G)_{mass} = 0.075 \frac{gm}{cm^2}$ $\qquad \rho_G = 0.001 \frac{gm}{cm^3}$

$\therefore \mu_F = 11.63$, $\mu_G = 0.0133$ and $L = 12.7$ cm.

Hence $K = L(\mu_F - \mu_G) = 147.6$

Let $K\alpha_A = 0.1$ $\qquad \therefore \alpha_A = 6.775 \times 10^{-4}$

$K\alpha_B = 0.8$ $\qquad \therefore \alpha_B = 5.42 \times 10^{-3}$

also

Let the slugs be periodic with a period T, then $t_1 = t_2/2 = T/2$.

From equation (E58)

$$\bar{\alpha} = 0.4500$$

From equation (E60)

$$\bar{\alpha} = 0.4518$$

When the gamma rays are parallel to the plane of phase separation, the relationship between 'α' and

'I_M' is linear,

$$\alpha = \frac{I_M - I_F}{I_G - I_F}$$

Hence by averaging 'I_M' in calculating 'α', no errors are introduced.

E.5 EFFECTS DUE TO FLUCTUATING VOID FRACTIONS

Apart from the errors introduced by the normal practice of averaging the intensity ratio rather than its logarithmic value, another effect does exist, and is due to the fluctuating void even when its average value over a time 'T' is equal to that actually measured. The analysis attempted here is similar to that carried out by Harms and Forrest (H19).

Referring to equation (E48)

$$R(t) = \frac{V_M(t)}{V_F(t)} = e^{\frac{\alpha(t)}{K}} \qquad \text{(E62)}$$

The measured value of R(t) averaged over a time 'T' is

$$\bar{R} = \frac{1}{T}\int_0^T e^{\frac{\alpha(t)}{K}}\,dt \qquad \text{(E63)}$$

In carrying out void fraction measurements, it is implicitly assumed that the void fraction is constant during the measurement interval, which hydrodynamically means a uniformly distributed flow. In this case $\alpha(t)$ is a constant value given by

$$\alpha(t) = \alpha_o \qquad \text{(E64)}$$

Hence

$$\bar{R}_o = e^{\frac{\alpha_o}{K}} = R_o \qquad \text{(E65)}$$

and

$$\alpha_o = K \ln (\bar{R}_o) \qquad \text{(E66)}$$

Let us now consider a fluctuating void fraction $\alpha_b(t)$ such that its time average value is equal to $_o$ where

$$\alpha_o = \frac{1}{T} \int_o^T \alpha_b(t)\, dt \qquad \text{(E67)}$$

Accordingly from (E63)

$$\bar{R}_b = \frac{1}{T} \int_o^T e^{\frac{\alpha_b(t)}{K}} \; dt$$

and the ratio $\bar{R}_b/R_o$ from (E65) is

$$\frac{\bar{R}_b}{R_b} = \frac{e^{-\frac{\alpha_o}{K}}}{T} \int_o^T e^{\frac{\alpha_b(t)}{K}} \; dt$$

$$\therefore \; \frac{\bar{R}_b}{R_o} = \frac{1}{T} \int_o^T e^{\frac{\alpha_b(t) - \alpha_o}{K}} \; dt \qquad \text{(E68)}$$

As can be seen the only condition whereby '$\bar{R}_b$' will equal 'R_o' is that $\alpha_b(t)$ is a constant with a value equal to α_o and that the condition imposed by equation (E67) is not enough.

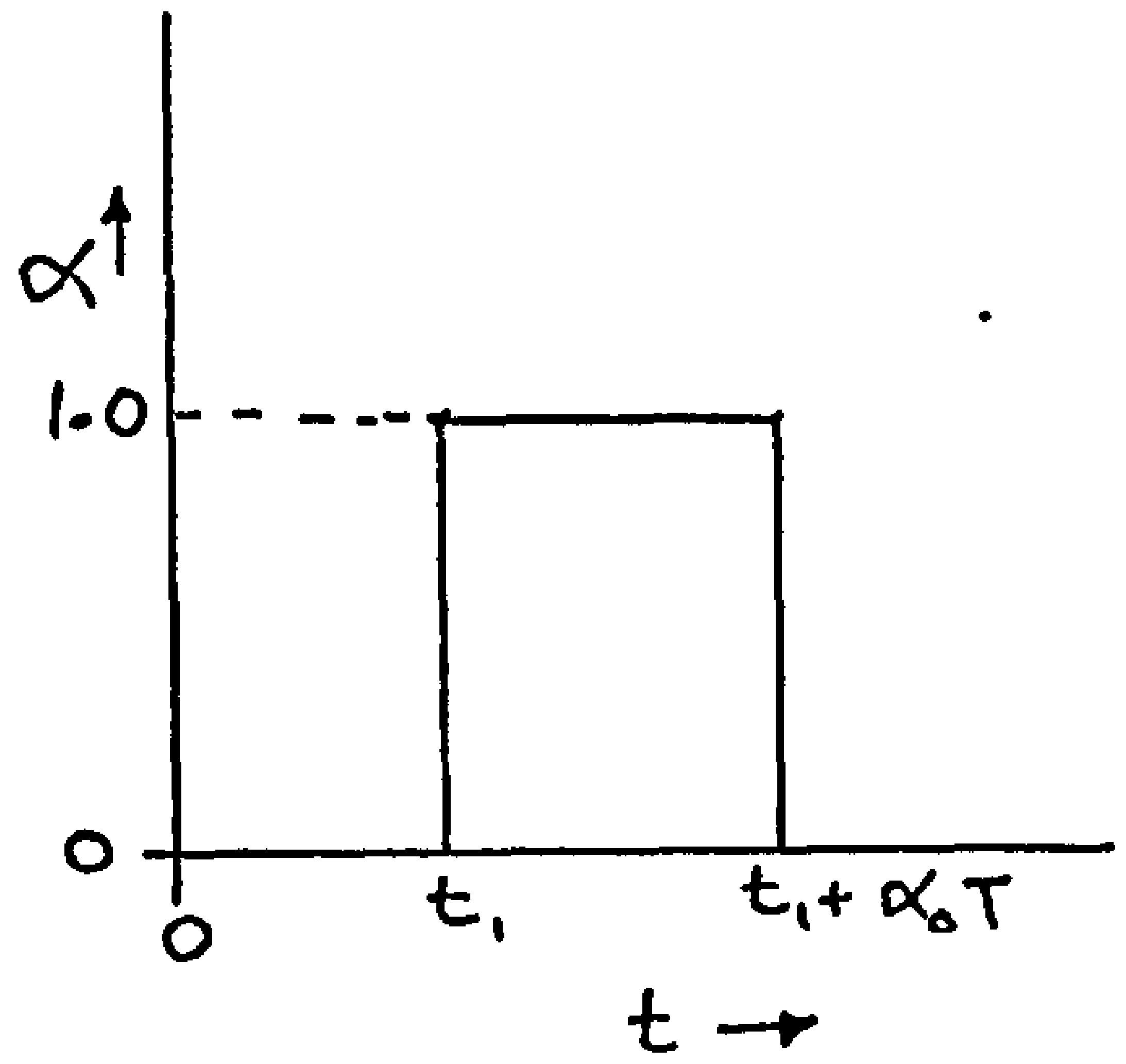
Let us consider, for example, the extreme case of void as shown in the figure below. Mathematically,

$\alpha_b(t) = 0 \qquad 0 \leqslant t \leqslant t_1$

$\alpha_b(t) = 1.0 \qquad t_1 \leqslant t \leqslant t_1 + {}_oT$

and

$\alpha_b(t) = 0 \qquad t_1 + \alpha_o T < t \leqslant T$



This was chosen to ensure that the average void fraction was equal to 'α_o' satisfying the condition of equation (E67).

The average value of 'R' follows from equation (E63) as

$$\bar{R} = \frac{1}{T}\int_o^T e^{\frac{\alpha(t)}{K}}\, dt$$

$$= \frac{1}{T}\left[\int_o^{t_1} dt + \int_{t_1}^{t_1 + {}_oT} e^{1/K}\, dt + \int_{t_1 + {}_oT}^{T} dt\right]$$

Remembering that $\alpha_o = \overline{\alpha_b}$, the above when solved gives

$$\bar{R} = \alpha_b(e^{1/K} - 1) + 1 \qquad \text{(E69)}$$

and

$$\bar{\alpha}_b = \frac{\bar{R} - 1}{e^{1/K} - 1} \qquad \text{(E70)}$$

From equation (E65)

$$\frac{\bar{R}}{R_o} = e^{-\frac{\alpha_o}{K}}\left[1 + \alpha_o(e^{1/K} - 1)\right] \qquad \text{(E71)}$$

What is actually measured is R_o (the voidage is assumed constant over the measuring interval, or

$$\bar{\alpha}_b = \frac{R_o - 1}{e^{1/K} - 1} = \frac{e^{\alpha_o/K} - 1}{e^{1/K} - 1} \qquad \text{(E72)}$$

The error in the measurement of '   ' is

$$\Delta\alpha = \alpha_o - \bar{\alpha}_b = \alpha_o - \frac{e^{\alpha_o/K} - 1}{e^{1/K} - 1}$$

and the percentage error is

$$\frac{\Delta\alpha}{\alpha_b}\,\% = (\alpha_b \frac{e^{1/K} - 1}{e^{\alpha_o/K} - 1} - 1) \times 100 \qquad \text{(E73)}$$

E.6 VOID FRACTION APPARATUS ARRANGEMENT, CALCULATION PROCEDURE AND STRATIFIED LAYER CALIBRATION

1. ARRANGEMENT AND ALIGNMENT OF APPARATUS:

To assemble the void fraction apparatus for measurements, the following steps were taken:

(i) The source holder and detector were set to lie in the same plane and opposite to each other, one on either side of the pipe.

(ii) Pieces of fine thread were used to simulate the paths of the γ -rays and the divergence required to scan the pipe. Adjustment of distance, i.e. 'source-tube' and 'tube-detector' for minimum divergence was carried bearing in mind the effect of distance on the γ-ray intensity arriving at the tube.

(iii) Lead collimators were inserted on both sides of the tube to confine the rays to the measuring plane, and to prevent rays not passing through the tube from reaching the detector. Step (ii) was repeated.

(iv) The apparatus was surrounded by lead brick shielding.

(v) The background radiation in the surrounding area was monitored, and extra shielding added whenever necessary.

Fig. E.8 is a schematic diagram of the arrangement for the 216 mm (8.5") pipe.

2. DETERMINING THE POTENTIAL DIVIDER CONSTANT OF THE BACKOFF UNIT:

The backing off voltage required to bring the electrometer reading to within the '0-300' mv of its metermovement was too large to be measured accurately, by a 100 mV range potentiometer. Hence, a potential divider was used to allow only 1/100th of this voltage to be measured by the potentiometer. The potential divider circuit is shown in Fig. E.9. Tests were carried out to accurately determine the value of the potential divider constant and these also afforded the opportunity of normalising the readings of the electrometer and potentiometer.

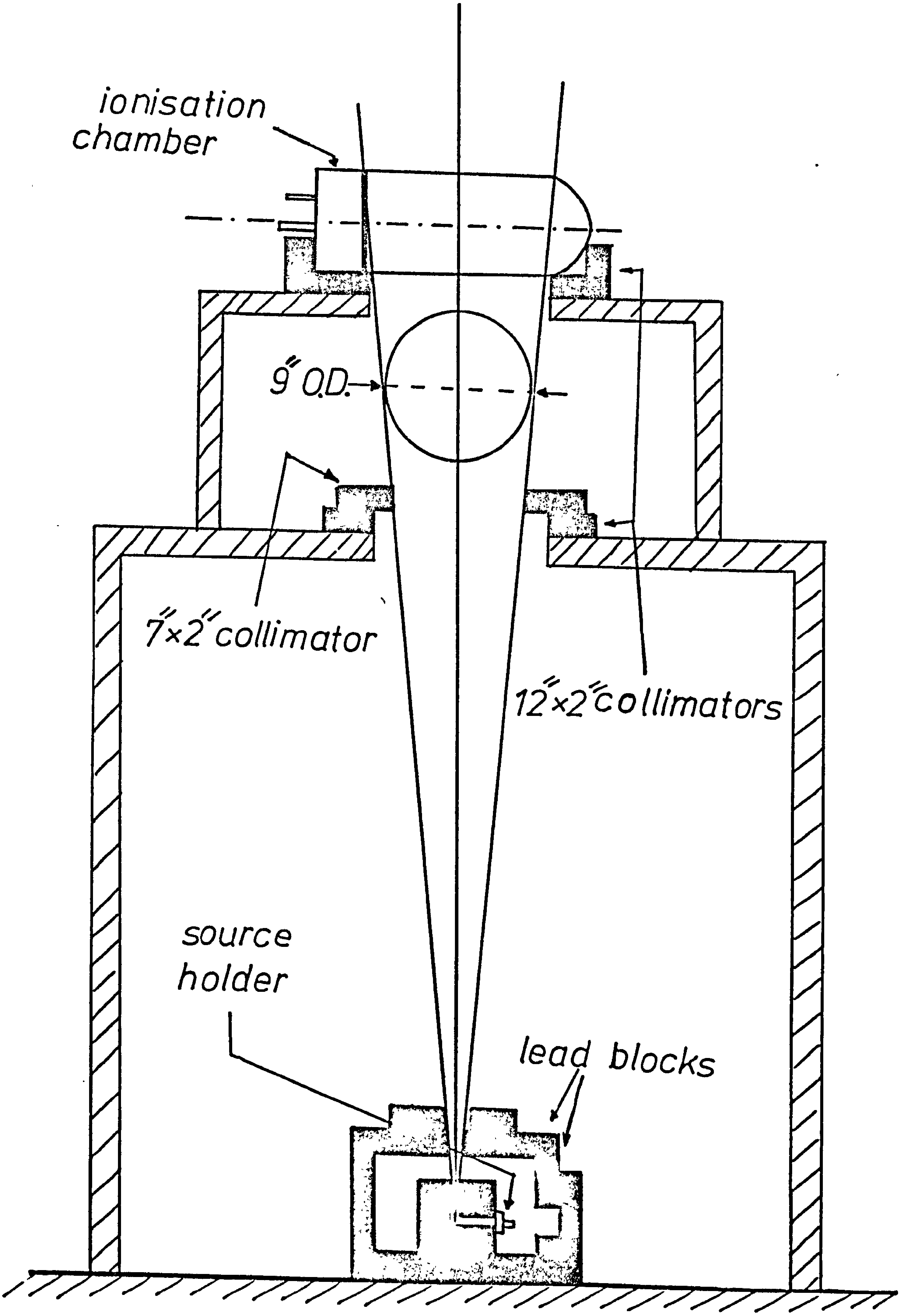


FIG. E8 VOID FRACTION MEASUREMENT SET UP

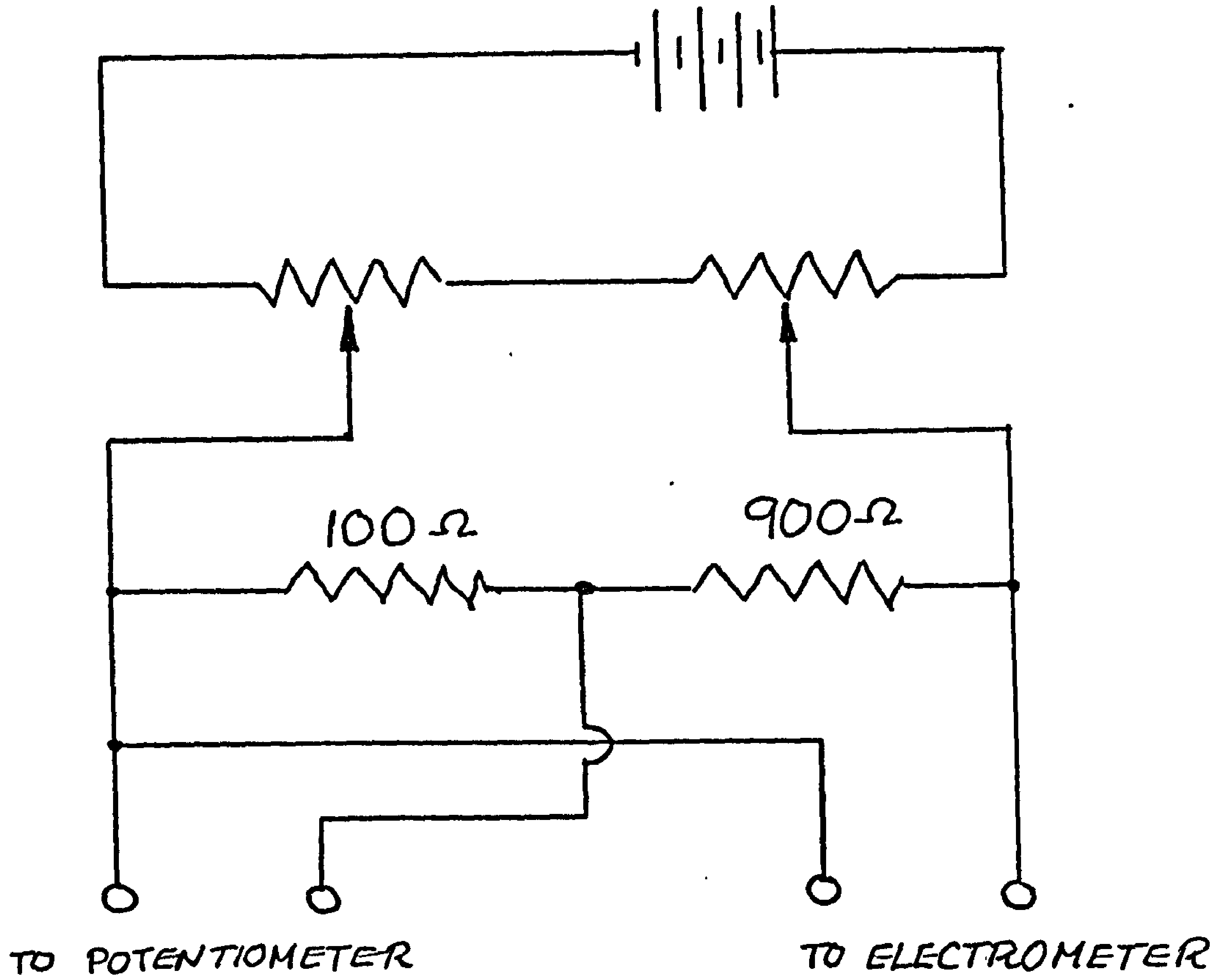


FIG. E9 POTENTIAL DIVIDER CIRCUIT FOR ELECTROMETER

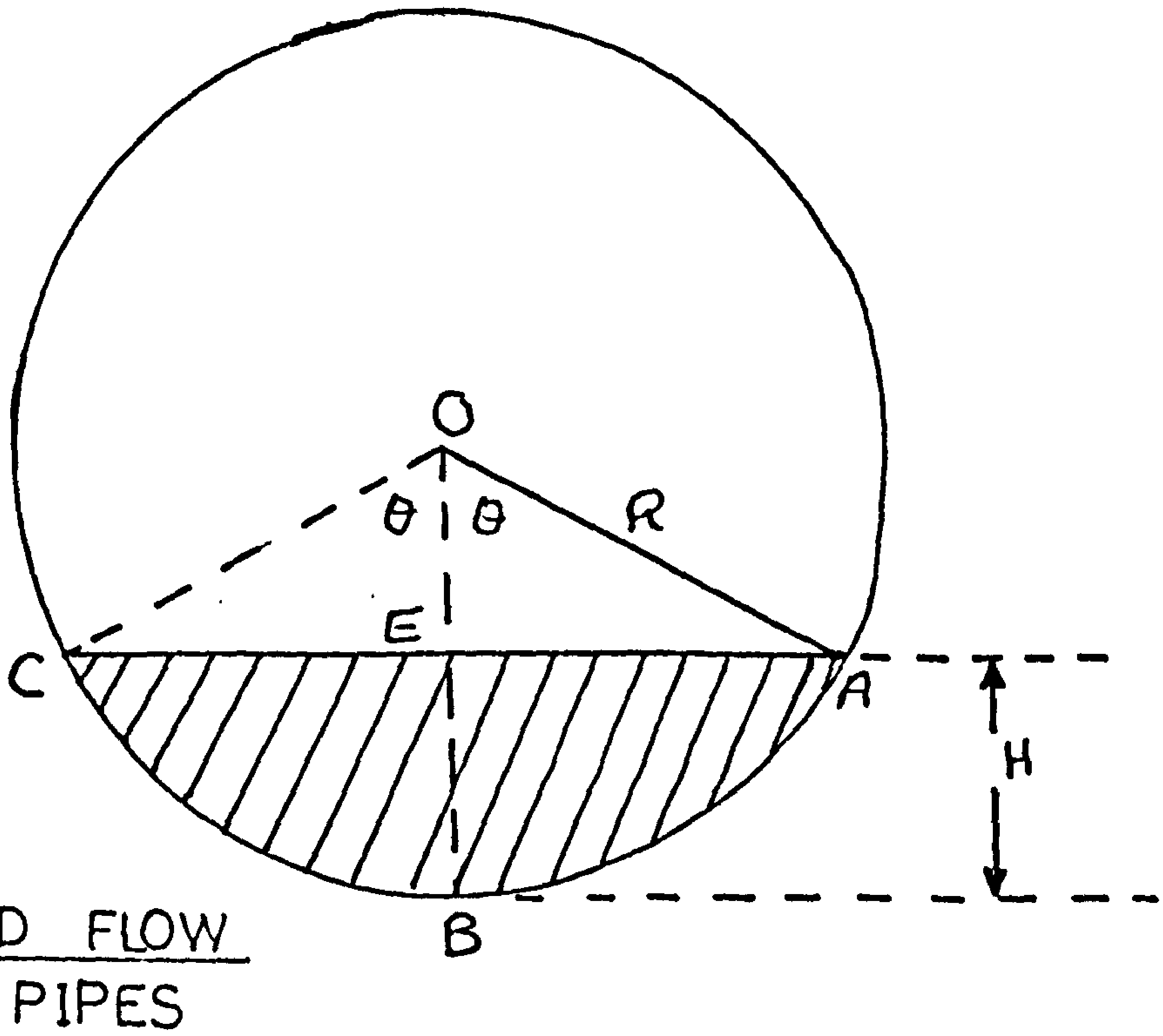


FIG. E10

STRATIFIED FLOW GEOMETRY IN PIPES

To start the test, the head amplifier (and hence ionisation chamber) was isolated from the electrometer by pressing the 'SHORT CIRCUIT' bottom on the head unit. The electrometer then behaved as a very sensitive voltmeter and a 'back off' signal was injected into the electrometer through the 'CALIBRATION' plug. A set of electrometer and potentiometer readings were noted. The potentiometer measured the voltage to within 1/100th of a millivolt, which meant that the actual 'back off' voltage was measured to the nearest mv. The results are shown in Fig. E.11 to give a linear relationship. The slope gives the 'correct' potential divider constant which was then used to convert the potentiometer readings into millivolts, matching up to the electrometer scale reading.

3. VOID FRACTION CALCULATION PROCEDURE:

Considering, for example, the stratified layer calibration which is detailed in the next section and illustrated in Fig. E.10, the first step in calculating 'α' was to determine the corresponding γ -ray intensities from the raw data. This was a straight forward procedure once the potential divider constant had been determined. The intensity expressed in mV is given by

$$I = ELE + CONST \times POT \qquad (E74)$$

where

ELE = Electrometer reading

CONST = Potential divider constant

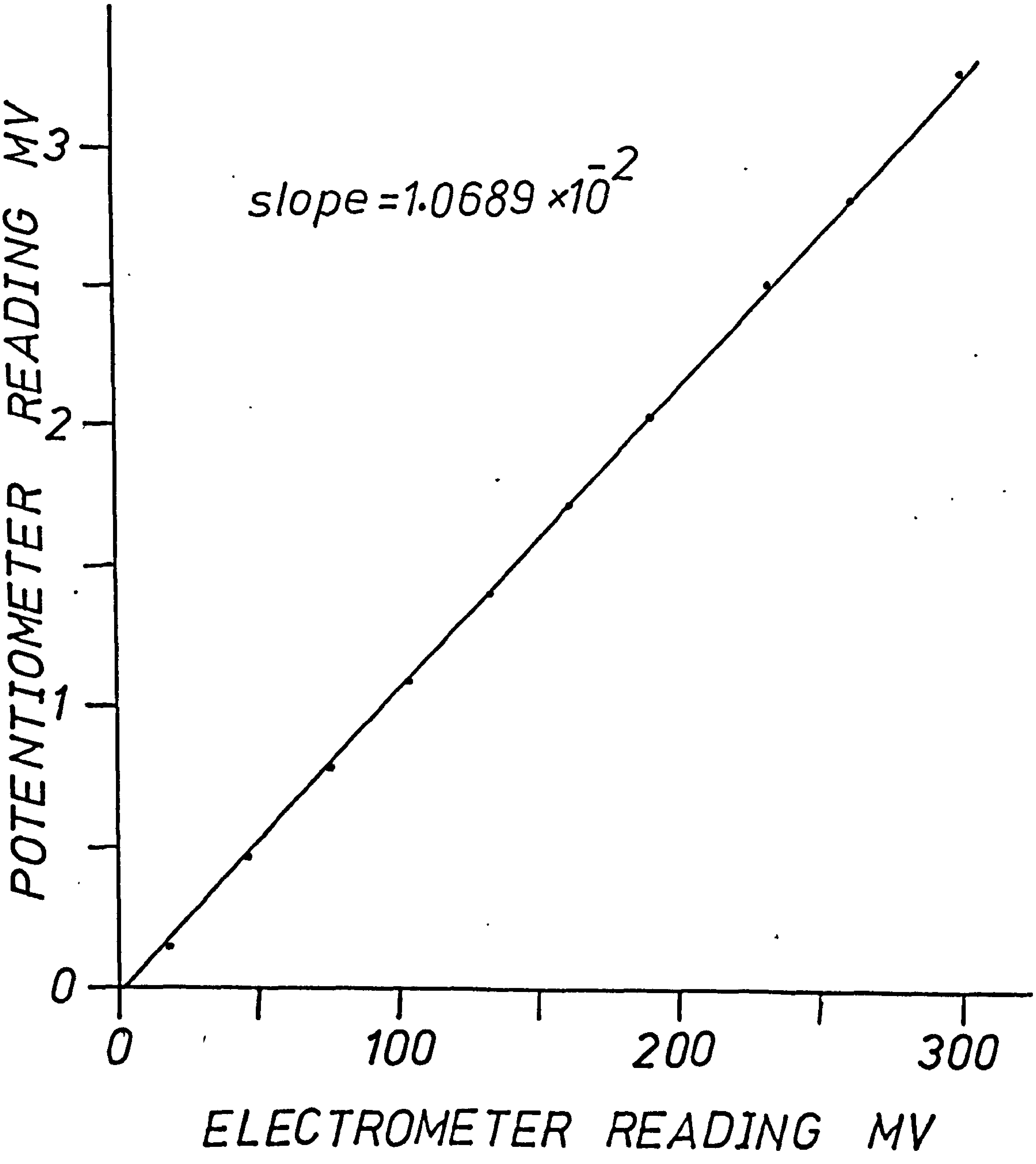


FIG. E11 POTENTIAL DIVIDER CALIBRATION

and POT = Potentiometer reading.

The term 'CONST x POT' represents the actual backoff signal in mV required to bring the signal to within the '0-300' mV scale of the electrometer. The intensity 'I_M' was then determined for each water level setting 'H' and the corresponding tube full 'I_F' and tube empty 'I_G' at that time. Referring to section E.2, the void fraction 'α' is given by either of the following relations depending on whether the rays are parallel or normal to the plane of phase separation,

$$\alpha = \frac{\ln (I_M/I_F)}{\ln (I_G/I_F)} \tag{E75}$$

or

$$\alpha = \frac{I_M - I_F}{I_G - I_F} \tag{E76}$$

Equation (E76) is recommended for calculating void fractions for a stratified layer with a horizontal gamma ray beam. Otherwise equation (E75) should be used.

4. STRATIFIED LAYER CALIBRATION

In order to carry out the in-situ calibration of a simulated stratified type flow, a piece of transparent perspex tubing was used with pieces of perspex sheets bolted to the two flanges blocking the two ends. A graduated piece of paper was stuck on both ends to allow liquid level measurements in the pipe. Provision was made for feeding fresh water into the pipe through one pressure tapping hole, while the air was allowed to escape through another tapping hole. The pipe was levelled such that the levels of water at both ends were the same.

The test procedure commenced by noting the tube empty intensity reading. Water was then introduced into the pipe and both water level and γ-ray intensity were recorded. More than 15 different levels of water were used to simulate different degrees of stratification until the pipe was completely full, tube tull of water reading then noted. The water level was decreased in steps also and the corresponding readings again noted.

To determine the void fraction corresponding to a given water level was a simple exercise in geometrical analysis. The problem reduced to determine the area of a segment of a circle as shown in Fig. E.10. The void fraction 'α' is simply

$$\alpha = \frac{\text{Area 'ABCEA'}}{(\pi/4)\ D^2} \qquad \text{(E77)}$$

From Fig. E.10.

$$\begin{aligned}\text{Area ABCEA} &= \text{Area of sector 'OABCO'} \\ &\quad - \text{Area of triangle 'OAECO'}. \\ &= \frac{2\theta}{2\pi}(\pi R^2) - 2\left[\tfrac{1}{2}(R-H)R \sin\theta\right]\end{aligned}$$

where

θ is in radians and $R = D/2$

$$\therefore \quad \text{Area ABCEA} = \theta R^2 - (R-H)\,R \sin\theta$$

But $\cos\theta = \frac{R-H}{R}$

$$\therefore \quad \theta = \cos^{-1}\left(\frac{R-H}{R}\right)$$

then

$$\sin\theta = \sqrt{1-\cos^2\theta} = \frac{1}{R}\sqrt{R^2-(R-H)^2}$$

$$\therefore \text{ Area ABCEA } = R^2\cos^{-1}\left(\frac{R-H}{R}\right) - (R-H)\sqrt{R^2-(R-H)^2}$$

From (E77)

$$\alpha = \frac{1}{\pi}\left[\cos^{-1}\left(\frac{R-H}{R}\right) - \frac{(R-H)}{R^2}\sqrt{R^2-(R-H)^2}\right] \qquad \text{(E78)}$$

APPENDIX F

PHOTOGRAPHIC TECHNIQUES

APPENDIX F PHOTOGRAPHIC TECHNIQUES

To improve the photographic results, a special photographic box was built to minimise optical effects caused by the curvature of the pipe. The box was approximately 0.61 m (2 ft) long, 0.3 m (1 ft) high by 0.3 (1 ft) wide and manufactured from 12.7 mm (0.5") perspex sheets. The box shown in Fig. F.1 was filled with water and designed such that it could be sealed around the pipe by two O-rings, one at each end. Other joints with smooth surfaces were self sealed by grease and bolted. Further sealing around the pipe joints was effected by using plasticine which was necessary due to vibrations of the rig.

All the box sides lying in a plane parallel to the pipe axis were covered with black cardboard except the side opposite to the camera which included a slit. Adjustments were made such that a full picture of the pipe was received through the camera lens. The edges of the box were painted black, from inside, with a matt finish.

The light was shone at an angle through the sides which were normal to the pipe, using two 1500 W mercury lamps with special reflector attachments, this system being adopted after a trial and error procedure.

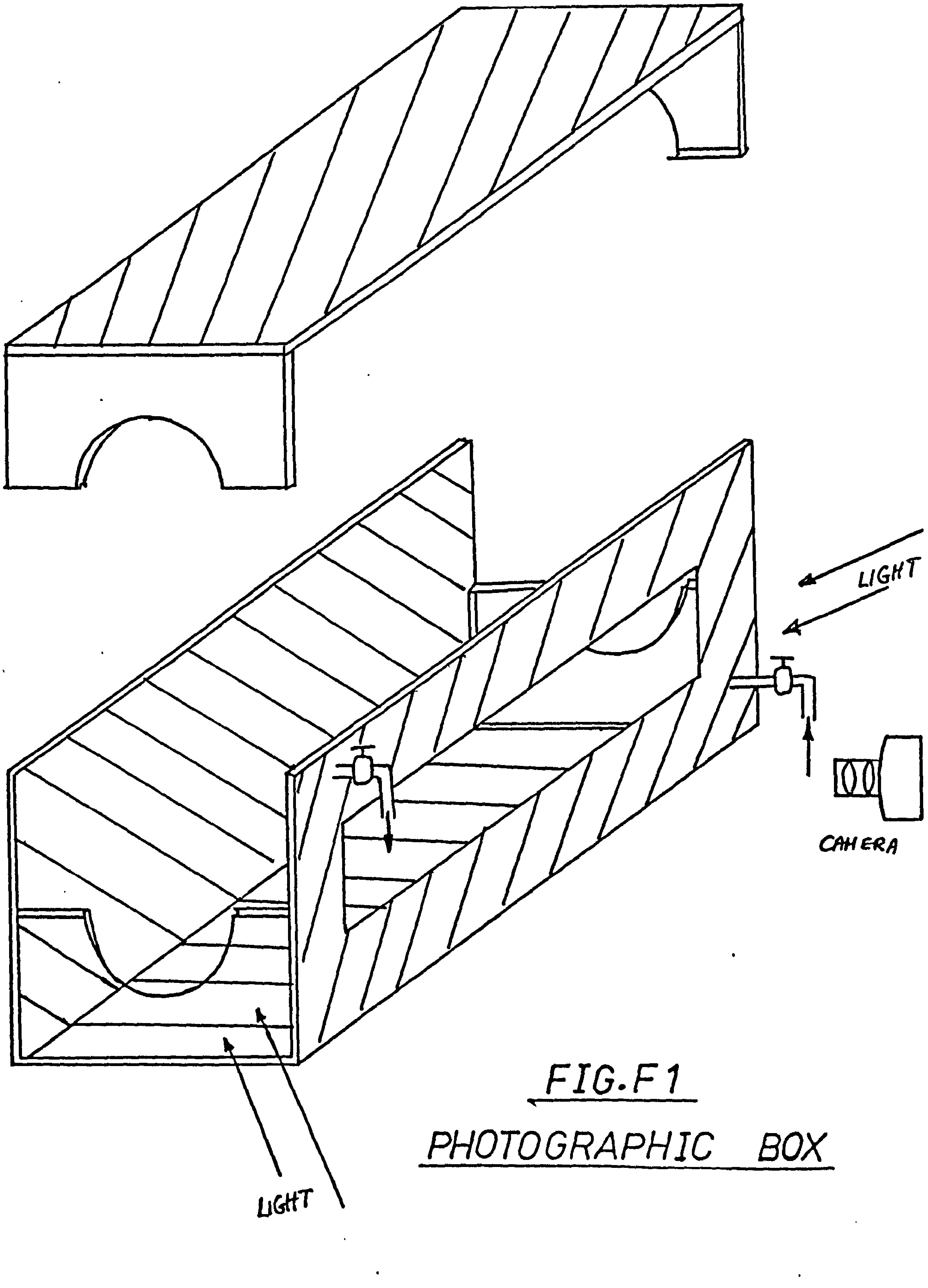


FIG.F1

PHOTOGRAPHIC BOX

APPENDIX G

PRESSURE TRANSDUCER CALIBRATION

APPENDIX G PRESSURE TRANSDUCER CALIBRATION

The pressure transducers were calibrated in situ in a length of 127 mm (5") bore perspex tubing using water. The calibration apparatus is shown in Fig. G.1. with a detail of the transducer fixing in Fig. G.2.

The circuit was pressurised either by a hydraulic pump or water mains pressure and corresponding readings of pressure and transducer output taken at steps up to, and down from, 50 psi absolute. Suitable corrections were made for difference in elevation between the pressure measuring level and the transducer level.

The calibration characteristics obtained are shown in Figs. G.3 and G.4 and, as can be seen, are linear with no hysteresis effects. The 50 psia (max. range) transducer was installed near the exit of test section, i.e. 14 m from mixer. The 100 psia (max. range) transducer on the other hand was located at 8 m from mixer.

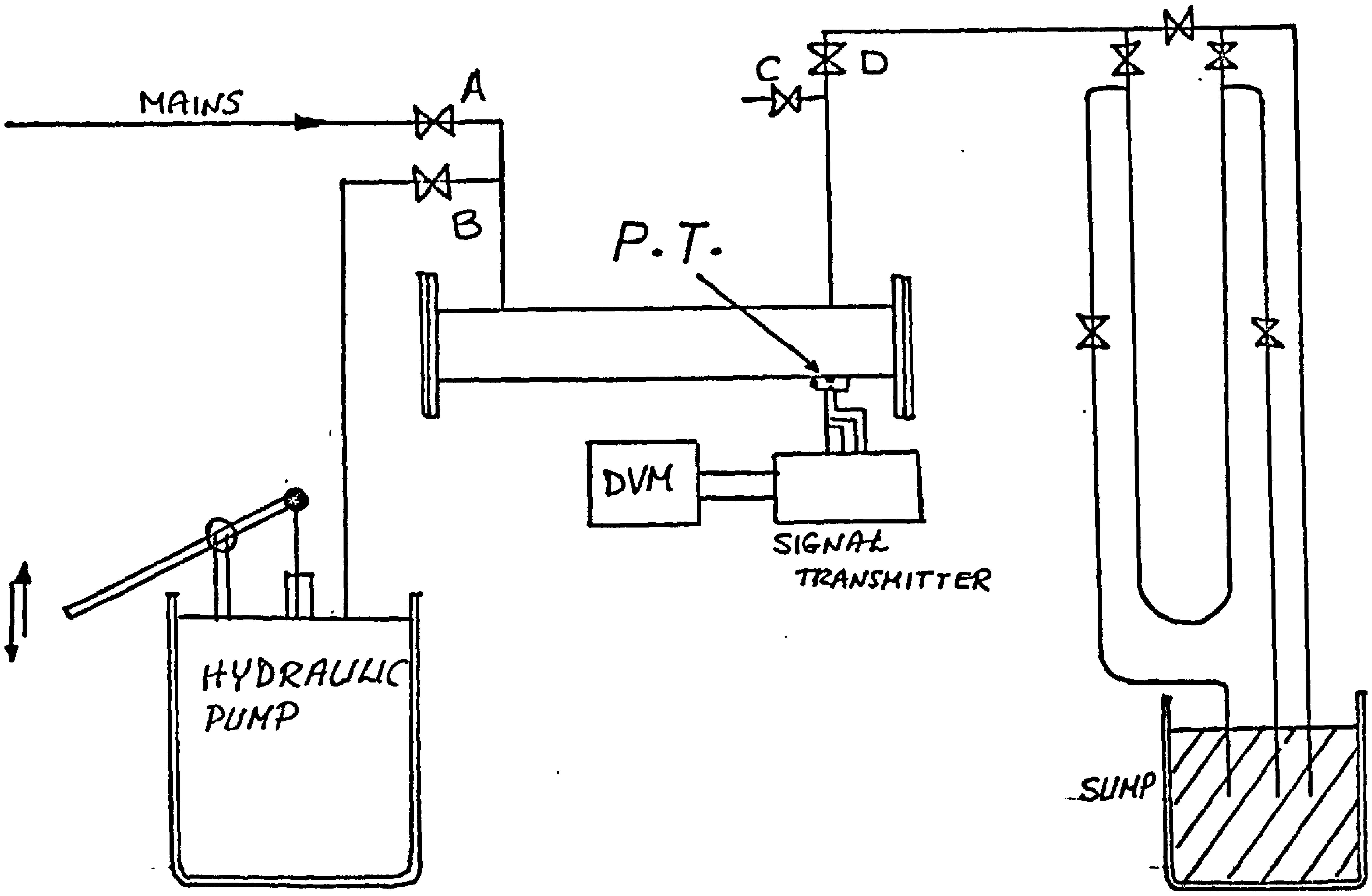


FIG. G1 CALIBRATION CIRCUIT

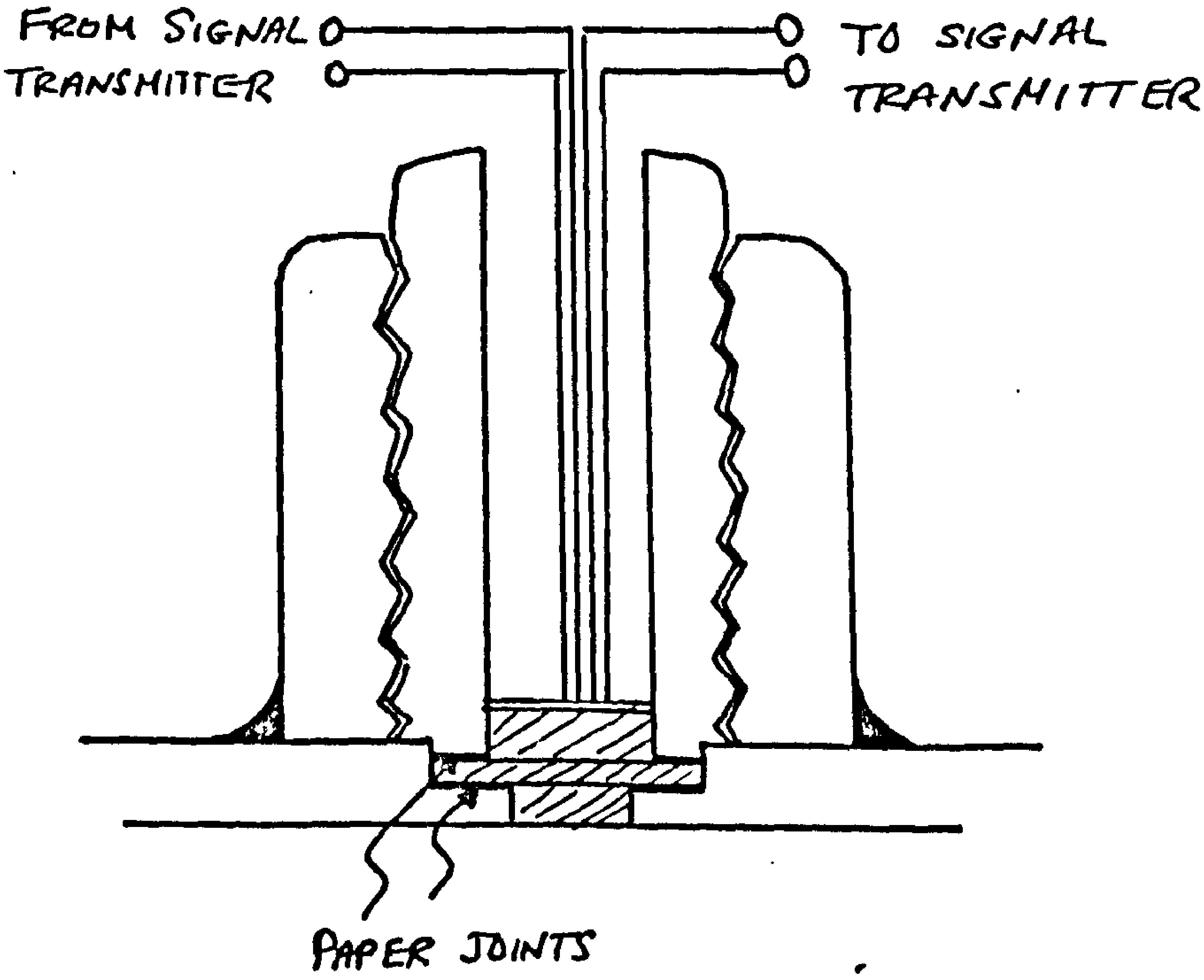
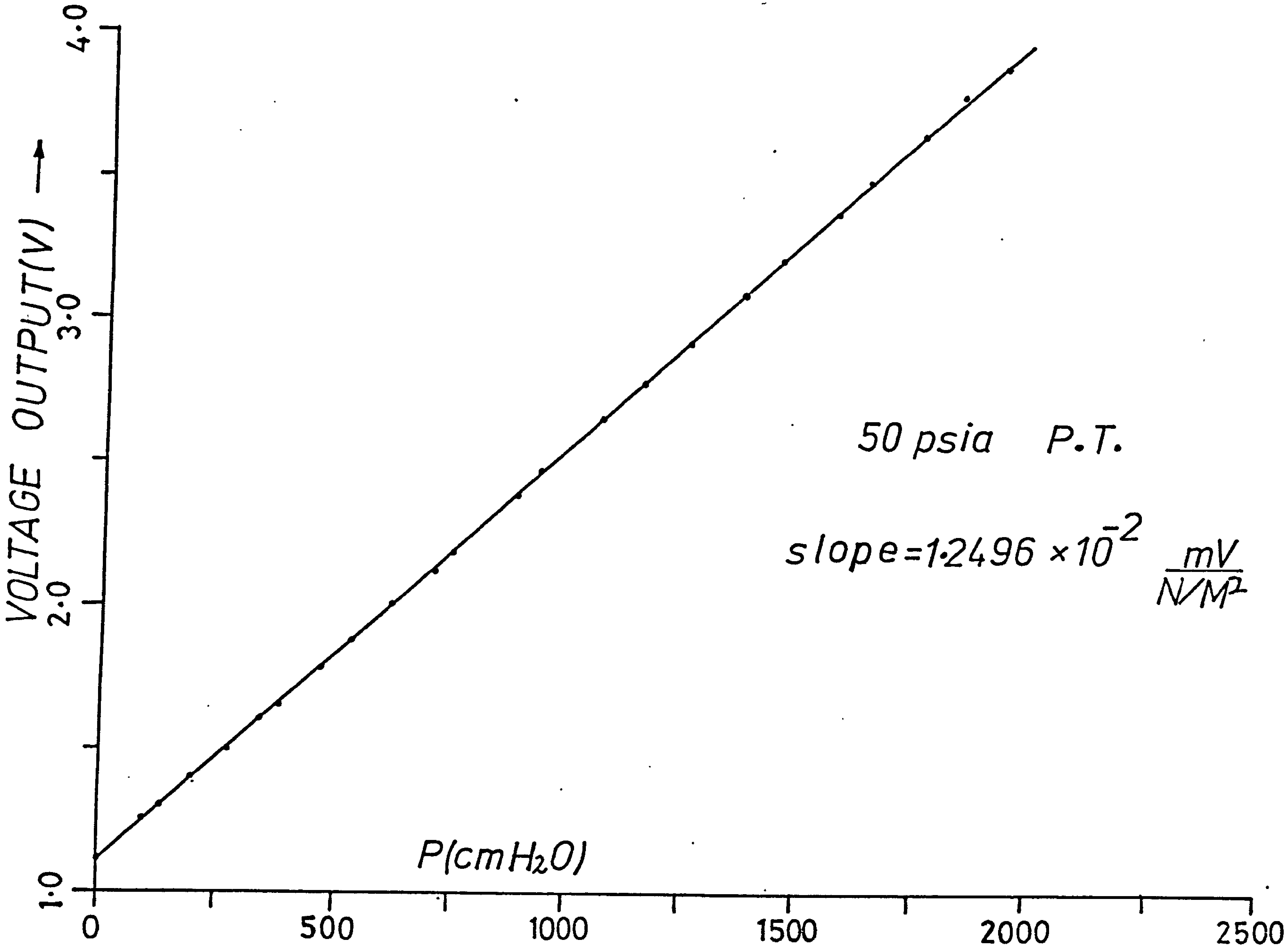
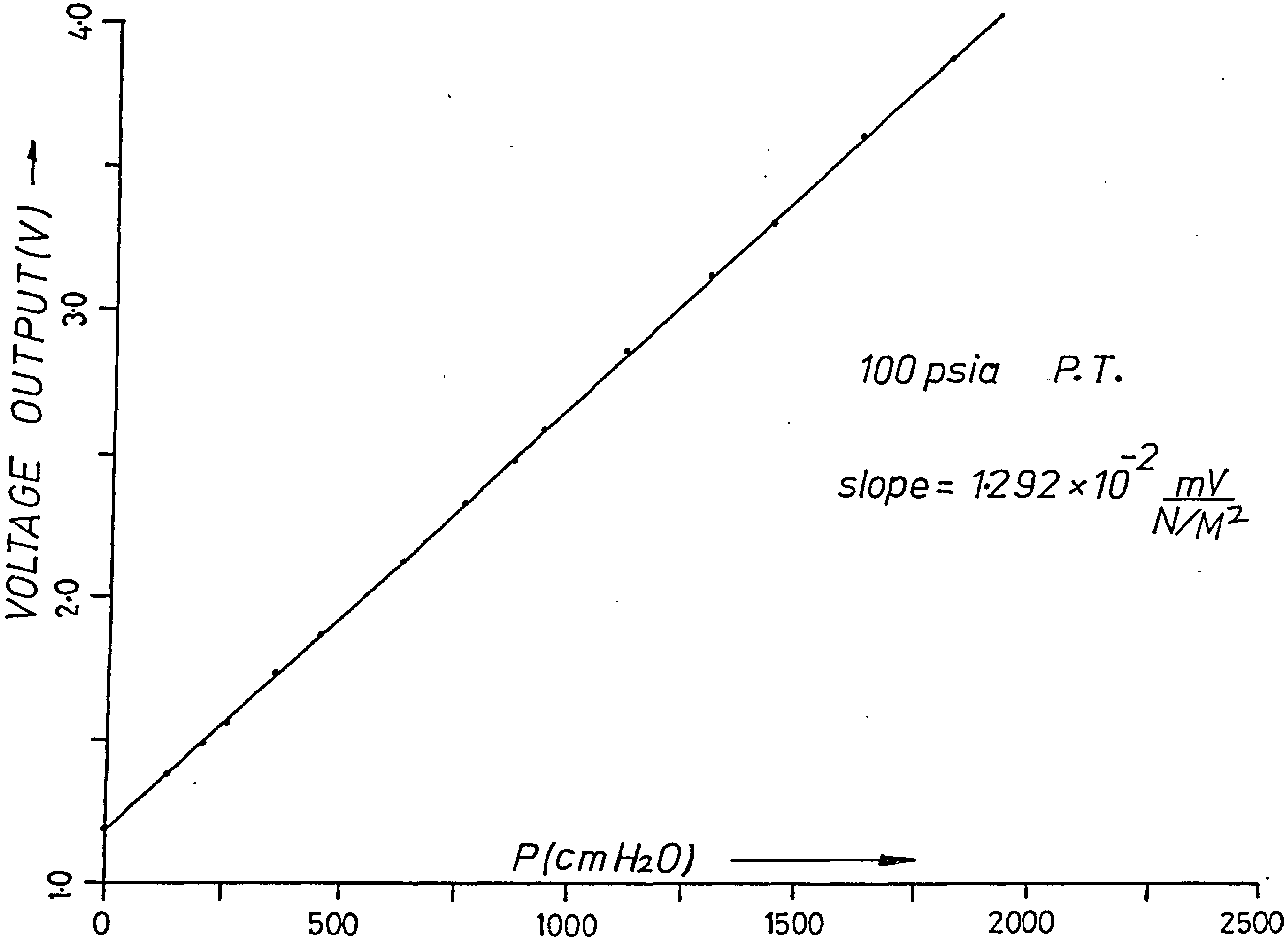


FIG. G2 TRANSDUCER BOSS ASSEMBLY



FIG·G3 P.T. CHARACTERISTICS



FIG· G4 P.T. CHARACTERISTICS

APPENDIX H

MULTI-FREQUENCY CRYSTAL OSCILLATOR

APPENDIX H MULTI-FREQUENCY CRYSTAL OSCILLATOR

1. THE CRYSTAL OSCILLATOR

In general, an oscillator is an electronic amplifier that generates a frequency which is determined by the value of its oscillatory components, and maintains that frequency to a certain accuracy. Positive feed back is used (i.e. output fed in phase to input) to reinforce the action in the amplifier and to supply the power lost during the generation of each cycle. Feed back may be accomplished by inductive, capacitive or resistive coupling between the amplifier output and input. Most oscillators may be classified as either tuned inductance-capacitance (LC) or relaxation resistance-capacitance (RC) type. For highly stable frequency characteristics, crystals may be used which possess an electro-mechanical property whereby a stress applied on the crystal causes polarisation and vice versa. Crystals are produced from 'piezoelectric materials', and the property is known as a 'piezoelectric effect'. Crystals can thus be used as a very sharp frequency selector (filter) allowing only the frequency equivalent to its resonant (natural) frequency to pass. Oscillators employing crystals are called'crystal oscillators' and are characterised by being exact, repeatable and stable.

The oscillator employed in this work was a three stage amplifier as shown in Fig. H.1. It produced square

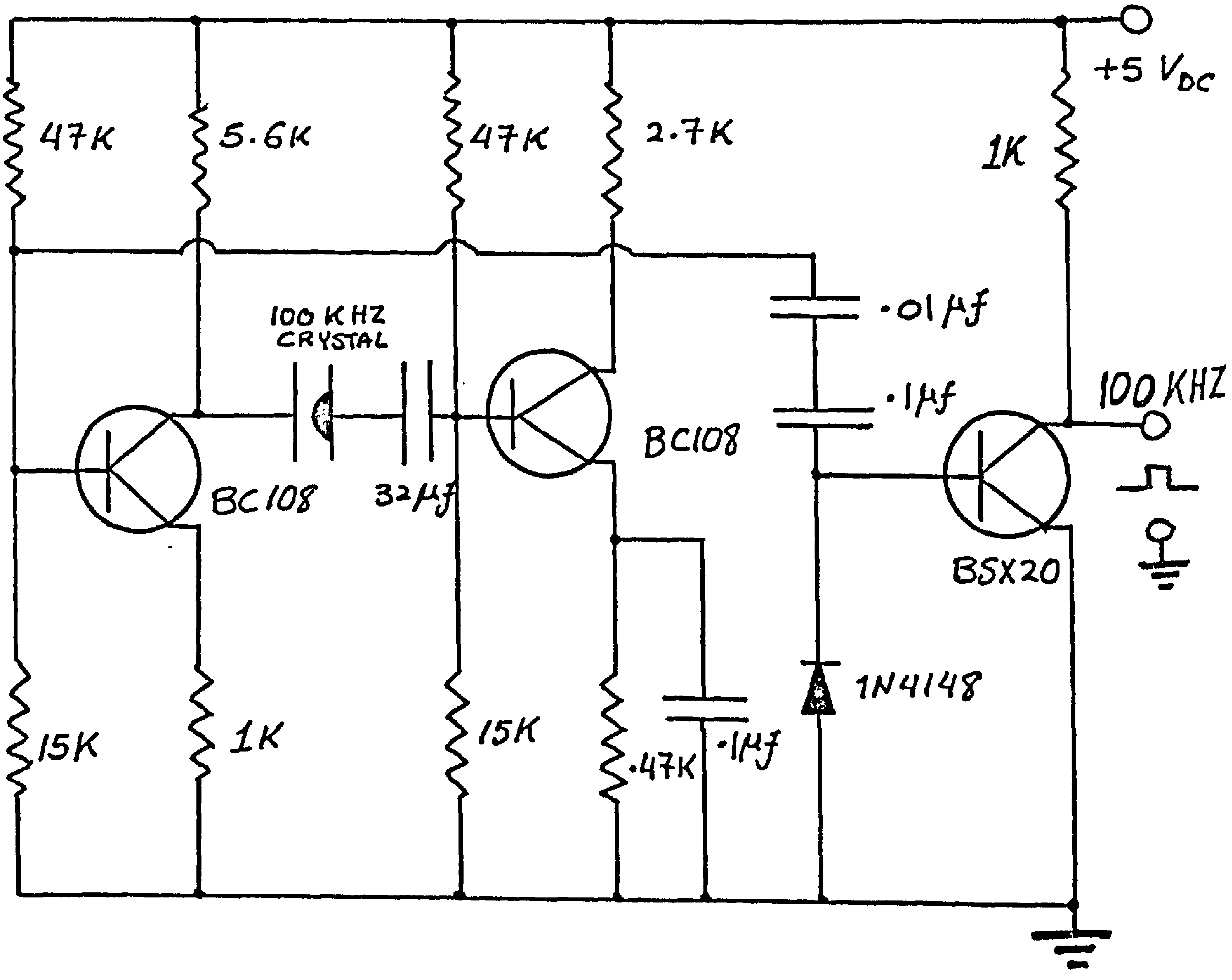


FIG. H1 CIRCUIT DIAGRAM OF CRYSTAL OSCILLATOR pulses of frequency equal to 100 K Hz and the operation was as follows:

Noise in the circuit was amplified in the 1st stage, then fed to the 2nd stage through the crystal which filtered out all frequencies except the natural frequency (i.e. 100 K Hz). Part of the output was fed back through the capacitor (0.01μF) to the input of the 1st stage, hence supplying the energy required to sustain the oscillation. The rest of the output was amplified in the 3rd stage to produce a 5 volts peak to peak symmetrical square pulses at 100 K Hz frequency. A transistor protection diode was connected to the base of the third transistor to prevent overload, and to keep the output pulse positive. The 100 K Hz signal was then passed to four 'divide by 10 counters' in series to produce 10 KHz, 1 KHz, 100 Hz and 10 Hz signals alternatively. The 1 KHz signal was used to produce 200 Hz and 40 Hz signals by using another two 'divide by 5 counters'. These counters were integrated circuits utilising monostable multivibrators.

The overall schematic diagram of the oscillator unit is shown in Fig. H.2.

2. THE POWER SUPPLY UNIT

The function of this unit was to supply the necessary power, in the form of a dc-voltage, required to operate the crystal oscillator, utilizing the mains 220 volts a.c. supply. It consisted mainly of a transformer,

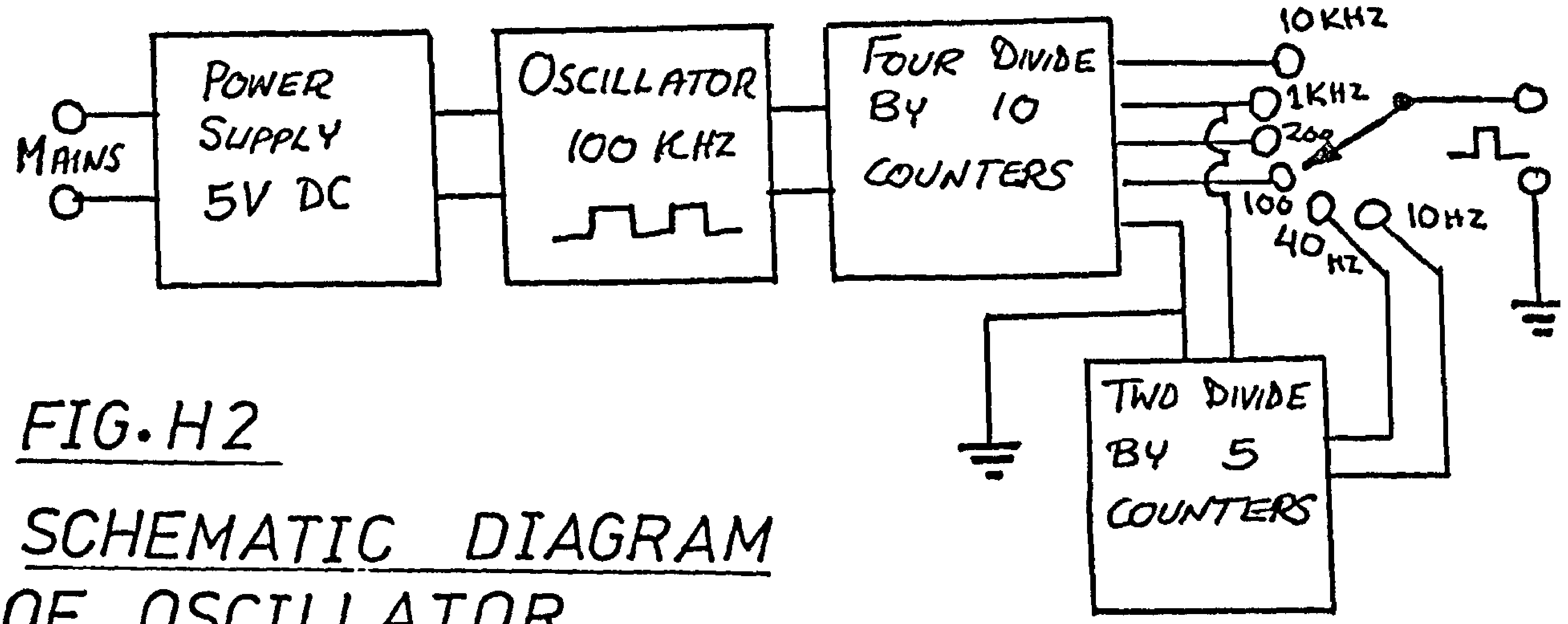


FIG. H2

SCHEMATIC DIAGRAM OF OSCILLATOR

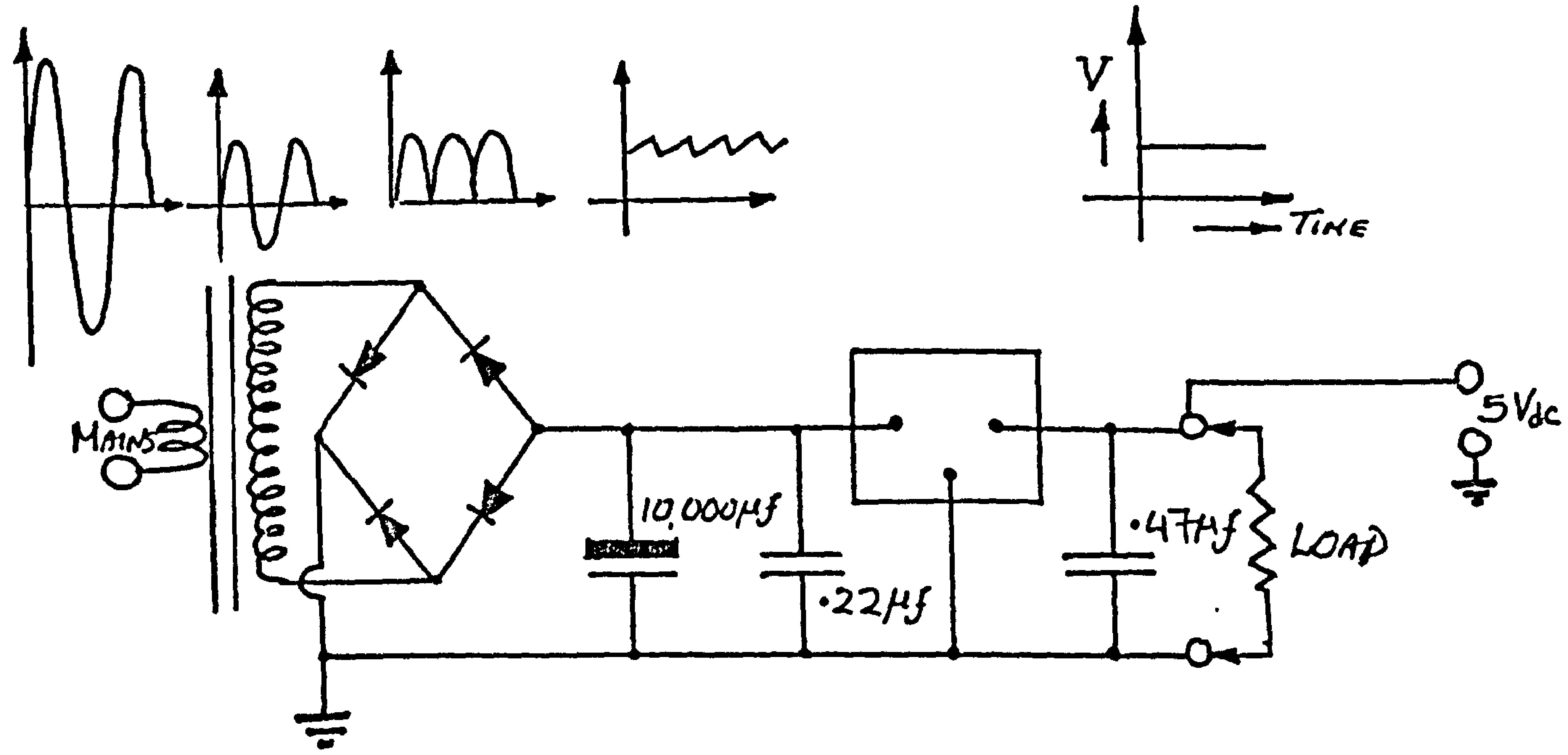


FIG. H3 CIRCUIT DIAGRAM OF POWER SUPPLY

rectifier, filter and regulator. The circuit diagram is shown in Fig. H.3. The shape of the waveform after each unit is also shown.

APPENDIX J

COMPUTER CONTROLLED DATA ACQUISITION SYSTEM

APPENDIX J COMPUTER CONTROLLED DATA ACQUISITION SYSTEM

1. GENERAL DESCRIPTION

The important features of the system are presented here but more detailed information can be obtained from the appropriate manuals.

The main equipment and peripherals used in the high speed data acquisition system are shown in Fig. 3.14 in the main text. It was based on a Hewlett-Packard 2100A computer with a 16 K of core store. Approximately 1000 K of back up store was provided by a cartridge disc-subsystem. Other peripherals include Paper Tape Reader, Paper Tape Punch, a Teletype, a Graph Plotter, Visual Display Unit (VDU), and Analogue to Digital Converter (ADC). All the peripherals were manufactured by Hewlett-Packard except for the V.D.U. and teletype which were Tektronic products. The computer had the facility of 'Direct Memory Access' (DMA), which permitted very fast access to the core (1,020,400 words per sec). The limitation on the speed of acquisition was imposed by the 'ADC' unit which could handle up to 100,000 data conversions per sec. A multiplexer in the 'ADC' unit allowed sequential conversion of up to 16 channels.

2. DATA ACQUISITION SYSTEM

Basically, there were two ways of using the computer for data collection. These will be referred to as the 'Non-Buffered' method and the 'Buffered' method.

The Non-Buffered method involved three distinct phases

(i) Data Acquisition phase: where the analogue input signals from up to 16 channels were converted to digital form and stored in the 16 K computer core.

(ii) Dump to Disc phase: where the data in the core was dumped on to the disc leaving the core available for data from subsequent runs. Once the data was on the disc they were a permanent record, but could be over-written when no longer required.

(iii) Processing phase: where the data was retrieved from the disc, processed and output obtained in any of four different ways

- (a) printed on the Teletype (or VDU).
- (b) graphically displayed on the VDU.
- (c) plotted on the Graph Plotter.
- (d) punched on paper tape.

All the operations in this phase were carried out under the control of a Disc-based Operating System, 'DOS-M'.

Operating with this method involved running three absolute binary programs stored on paper tape. These were the data acquisition tape, the core to disc transfer tape and the DOS-M bootstrap tape (details of the contents and method of operating these tapes are given in the computer manual).

The Buffered method was similar to the Non-Buffered method except that phases (i) and (ii) were merged into one operation. The analogue signals were converted to digital form and stored temporarily in a buffer zone in core. When this buffer zone was full, fresh data were loaded into a second buffer whilst the first buffer was being dumped to disc. By the time the second buffer was full, the first buffer was empty and fresh data were loaded there again.

The buffered acquisition program was provided by Hewlett-Packard and was an 'Absolute Assembler' program. The version provided stopped excusion after three buffer dumps. The way the data were stored on the disc was exactly the same for both methods of acquisition. The same processing programs could therefore be used to retrieve data from disc by both methods.

The first method was used for the data collection in these experiments.

3. DATA ACQUISITION PROCESS

The analogue signals must be conditioned to lie within ± 1 volt before being fed to the ADC. They could be monitored on an oscilloscope or recorded on a UV recorder. To provide easy access to the input of the 'ADC' an 'overload protect and monitor box' was provided with 32 BNC sockets (16 input sockets and 16 monitor sockets).

The ADC had a multiplexer unit which permitted sequential conversion of up to 16 signals and took a 10 μsec to perform conversion from analogue to digital form with a sensitivity of $\sim \pm$ 2 mV (i.e. '1000/512').

Operation of the multiplexer and converter was controlled by instructions from a running program in the Computer. To instruct the system to multiplex the input channels, trigger pulses were provided from either an external signal generator or a device on the rig. In these experiments an external signal generator was used (Appendix H).

APPENDIX K

CURVE FITTING SUBROUTINE

APPENDIX K CURVE FITTING SUBROUTINE AND PROGRAMME

A N.A.G.* library subroutine No. E02ABF was used on the ICL 1904S computer to evaluate the coefficients 'a_i' of the best fit, Nth degree polynomial. The variable 'y' was expressed in terms of the variable 'x' through the equation

$$y = \sum_{i=0}^{N} a_i x_i .$$

The subroutine calculated a weighted least-squares polynomial approximation of a set of data point using 'Forsythe's' method applied to orthogonal polynomials. It required the following input information

(i) Number of data points, M (max. = 200).

(ii) Degree of the highest order polynomial required (max. = 50).

(iii) One dimensional array of x-values of dimension at least M.

(iv) One dimensional array of y-values of the dimension at least M.

(v) One dimensional array of weights given to each point (x,y). In our case, a weight value of 1.0 was given to each point.

The output from the subroutine contained the coefficients of the polynomial found, and a measure of degree of fit.

---

* N.A.G. stands for 'Nottingham Algorithm Group'.

A program was written which incorporated this subroutine and output in addition to the coefficients of the polynomial, the x and y input values, the calculated y value and the percentage error. The program is given below.

Nomenclature

TMCM : Y-array values

B : X-array values

W : Weighting factor, normally = 1

P : Coefficient of polynomial

SI : Degree of polynomial

S : Predicted Y-value by the polynomial

R : Percentage error

M : Total no. of points

K1 : Degree of the polynomial required.

Program

```
       LIBRARY(SUBGROUPNGEF)
       PROGRAM (FARIS)
       COMPACT
       INPUT5=CR0
       OUTPUT6=LP0
       TRACE 2
       END
       MASTER FARIS
       DIMENSION B(400),TMCM(400),W(400),P(400),SI(400)
       LOGICAL L
       L=.FALSE.
       NN=5
       K1=1
       M=9
       KK=0
30     DO 10 I=1,M
       READ(5,100)TMCM(I),B(I)
       W(I)=1.0
10     CONTINUE
100    FORMAT(2F0.0)
```

```
C
C     TO GET POLY. FITS OF DIFFERENT ORDERS
C
      DO 5 I2=1,NN
      K1=K1+1
20    CALL E02ABF(M,B,TMCM,W,K1,N,SI,P,L)
      WRITE(6,50)
50    FORMAT(1H1,44H LEAST SQUARES FIT BY ORTHOGONAL POLYNOMIALS,
     17H E02ABF)
      WRITE(6,150)
150   FORMAT(////5X,15HCOEFFICIENTS OF,10X,8HGOODNESS/5X,
     115HBEST POLYNOMIAL,11X,6HOF FIT)
      DO 2 I=1,K1
      WRITE(6,250)P(I),SI(I)
2     CONTINUE
250   FORMAT(E24.10,E24.10)
      WRITE(6,400)N
400   FORMAT(//19HDEGREE OF BEST POLY,I4)
      WRITE(6,200)
200   FORMAT(////5X,4HLVFR,12X,4HTMCM,12X,3HFIT,9X,8H% ERROR )
C
C     TO CALCULATE THE FIT AND THE RESIDUAL.
C
      DO 3 J=1,M
      T2=B(J)
      N1=N+1
      S=P(N1)
      DO 4 I=1,N
      I1=N1-I
      IF(I1.EQ.0)GO TO 6
      S=S*T2+P(I1)
      GO TO 4
6     S=S*T2
4     CONTINUE
      R=S-TMCM(J)
      R=(R/TMCM(J))*100.0
      WRITE(6,300)T2,TMCM(J),S,R
3     CONTINUE
300   FORMAT(4E15.6)
5     CONTINUE
      K1=1
      KK=KK+1
      IF(KK.LT.5)GO TO 30
      STOP
      END
      FINISH
```

APPENDIX L

DIFFERENCES BETWEEN PHASE 1, PHASE 2, AND PHASE 3 TESTS

APPENDIX L DIFFERENCES BETWEEN PHASE 1, PHASE 2, AND PHASE 3 TESTS

1. EXPERIMENTAL ARRANGEMENT

(i) In phase 1 and phase 2 tests, the test section was manufactured from 127 mm (5") bore perspex tubes in 2m lengths with flanges made from 12.7 mm ($\frac{1}{2}$") perspex sheets. In phase 3 tests, the complete test section was manufactured outside the University to an almost similar design, except that the tube lengths were 1.2m and the diameter 216 mm (8.5").

(ii) Due to the larger diameter tubes used in the phase 3 tests, the complete pipework had to be lifted $\sim$ 50 mm (2") to accommodate the tank height.

(iii) For phase 2 and phase 3 tests, the transparent viewing lengths on either side of bend 'B' were removed.

(iv) In phase 3 tests, the mixing section was designed to converge directly to the pipe diameter (127mm) without requiring another convergent channel as before. In phase 1 tests, the mixing chamber was located 55 pipe diameter upstream of bend 'B', where as it was inserted just after bend 'C' in phase 2 and phase 3 tests.

(v) For phase 3 tests valve C_4 was removed. It was kept fully open in phase 1 and phase 2 tests.

(vi) The same exit piece was used for all phases. For phase 3 tests, this meant the manufacture of a sandwich piece to connect the 216 mm (8.5") ID exit bend to the 127 mm (5") perforated exit piece.

2. INSTRUMENTATION AND DATA COLLECTED

(i) The high speed data acquisition system was employed to collect data in phase 2 and phase 3 tests only.

(ii) When measuring void fraction by the γ-ray attenuation technique, the γ-ray beam was shone vertically upwards in phase 3 tests. In phase 1 and phase 2 tests it was shone horizontally.

(iii) Ciné photography was employed during phase 1 tests only, while normal photography was employed in phase 1 and phase 2 tests only.

(iv) In phase 3 tests an attempt was made to measure the two phase pressure drop in each phase simultaneously when separated flows existed.

APPENDIX M

TRANSLATION OF EXPERIMENTAL READINGS

APPENDIX M TRANSLATION OF EXPERIMENTAL READINGS

Phase 1, Specimen Test Run No. 100109

Water temperature = 26.5^{o}C

Head difference across water flow orifice h_L = 24 cm H_2O

Air flow orifice upstream pressure P_g = 1.33 bar gauge

Air flow orifice upstream thermocouple emf = 0.62 mv.

Head difference across gas flow orifice S = 209.2 cm H_2O

Barometric pressure = 1.013 bar

Void fraction apparatus:

Electrometer reading = 180 mv

Potentiometer reading = 47.32 mv

Pressure gradient along the test section = 540 mm H_2O at 15^{o} inclination, over 6m.

Pressure at test section P = 1026 mm H_2O gauge.

Calculations

Air temperature $= \frac{24}{0.95} \times 0.62 = 15.66^{o}C$ (Appendix B)

Water density $\rho_f = 996.7 \ \frac{Kg}{m^3}$ (Appendix N)

Water volume flow rate $Q_f = \frac{1.45}{30} \times \frac{\sqrt{24}}{35.315} \ m^3/s$

$= 0.0067 \ m^3/s$ (Appendix B)

Mass flow of water $= {}_f Q_f = 6.683$ Kg/s

Air density $\rho_g = 1.293 \ (\frac{H}{76}) \ \frac{1}{1 + 0.00367t} \ \frac{Kg}{m^3}$

(Appendix N)

$$H = \frac{P}{135.5} + 76$$

$$\therefore \rho_g = 1.296 \quad Kg/m^3$$

$$\text{Mass flow of air} = 1278.98 \left\{ \left[\frac{P_{g\ abs.} \times 14.5}{100} \times \frac{1}{(1.8t + 492)} \right]^{\frac{1}{2}} \times \left(\frac{h_A}{2.54}\right)^{\frac{1}{2}} \times 0.4536 \right\} \quad \text{(Appendix B)}$$

$$= 1278.98 \left\{ \left[(133 + 101.33) \times \frac{14.5}{100} \times \frac{1}{(1.8 \times 15.66) + 492} \right]^{\frac{1}{2}} \times \left(\frac{209.2}{2.54}\right)^{\frac{1}{2}} \times 0.4536 \right\}$$

$$Mg = 1345.71 \quad Kg/h$$

Orifice plate correction factor (B.S. 1042) = 0.968

(Appendix B)

$$\therefore Mg = 1302.65 \ \frac{Kg}{h} = 0.3618 \ \frac{Kg}{s}$$

$$Q_g = \frac{0.3618}{1.296} = 0.2792 \quad m^3/s$$

Pressure drop along test section:

Corrected head loss = 540 mm H_2O at 15° inclination, over 6m.

$$\therefore \text{Pressure gradient} = 540 \times \frac{9.806}{1000} \ \frac{\sin 15^\circ}{6}$$

$$= 0.2284 \ \frac{KN}{m^3}$$

Void fraction:

Calibration: tube empty I_G = 4937 mv

tube full I_F = 2674 mv

Test:

$$I_F = 130 + (93.42 \times 27.61)$$

$$= 2709 \text{ mv}$$

$$I_M = 180 + (93.42 \times 47.32)$$

$$= 4600 \text{ mv}$$

$$\therefore \quad \alpha = \frac{\ln(I_G/I_F)}{\ln(I_M/I_F)} = 0.8635$$

APPENDIX N

COMPUTER PROGRAM FOR CONVERSION OF MEASURED QUANTITIES INTO USEFUL RESULTS

APPENDIX N COMPUTER PROGRAM FOR CONVERSION OF MEASURED QUANTITIES INTO USEFUL RESULTS

The first step in developing this program was to relate the air and water properties as functions of temperature and pressure, and to express the calibration curves, correction factors etc. in an equation of the form

$$y = f(x) = \sum_{n=0}^{N} a_n x^n$$

This was done with the help of a curve fitting computer library subroutine as explained in Appendix (K). Most of these equations have already been mentioned in the appropriate Appendices; the others are given below

1. Air Properties:*

(i) $$\rho_g = \frac{1.293}{1 + 0.00367t} \; \frac{H}{76} \qquad \frac{Kg}{m^3}$$

where H is the pressure in cm Hg and t in ^oC.

(ii) The dependence of air viscosity on temperature is shown in Fig. N1 and was expressed by the equation,

$$10^{-5}\mu_g = f_{(t)} \; \frac{NS}{m^2} = \sum_{n=0}^{2} a_n \, t^n$$

where

$a_o = 1.70744$ $\qquad a_1 = 0.00612487$

$a_2 = 0.000031396$

---

*The data were taken from: Handbook of Chemistry and Physics, 53rd edition, 1972-1973, Editor: R.C. Weast.

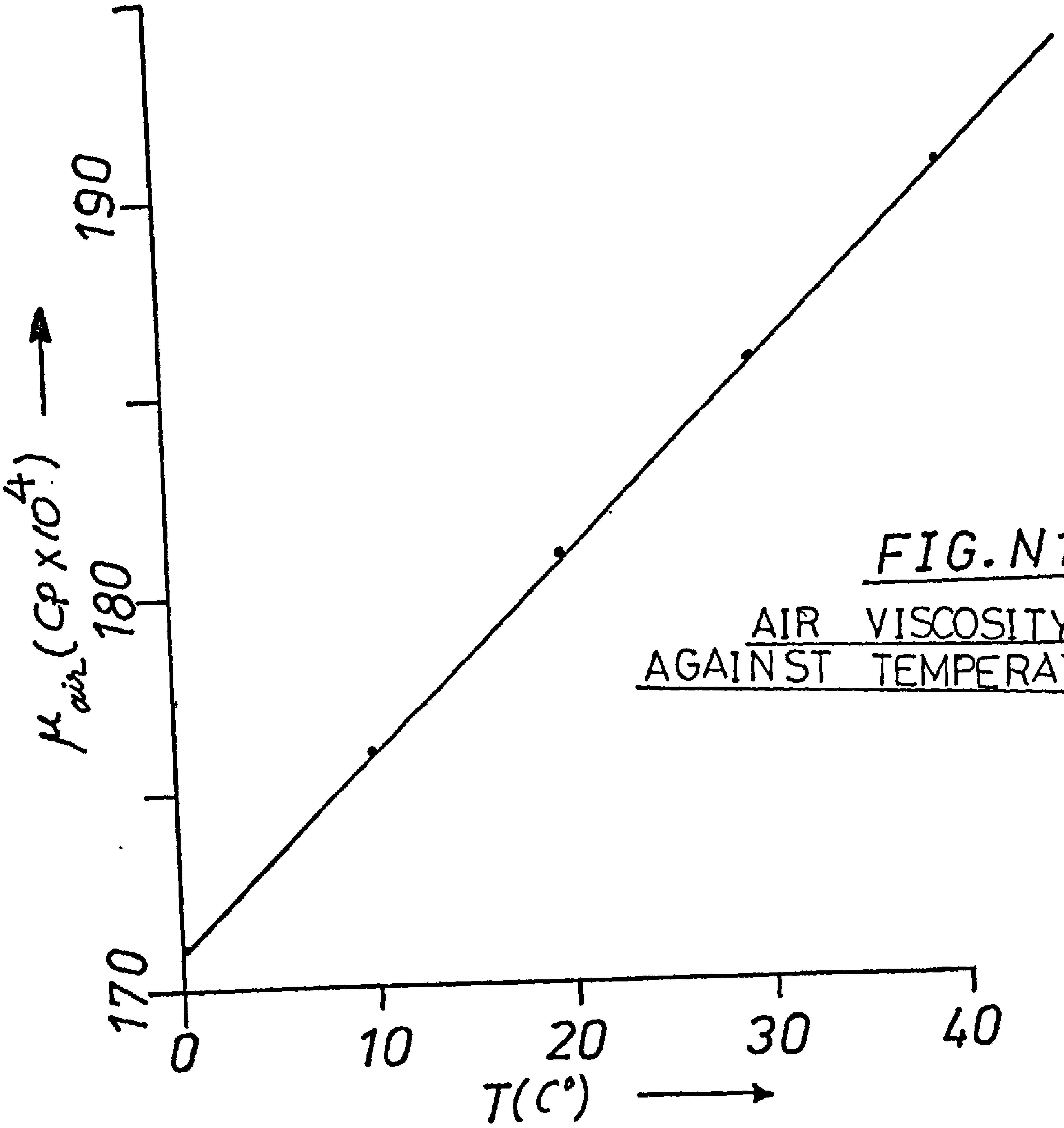


FIG. N1

AIR VISCOSITY AGAINST TEMPERATURE

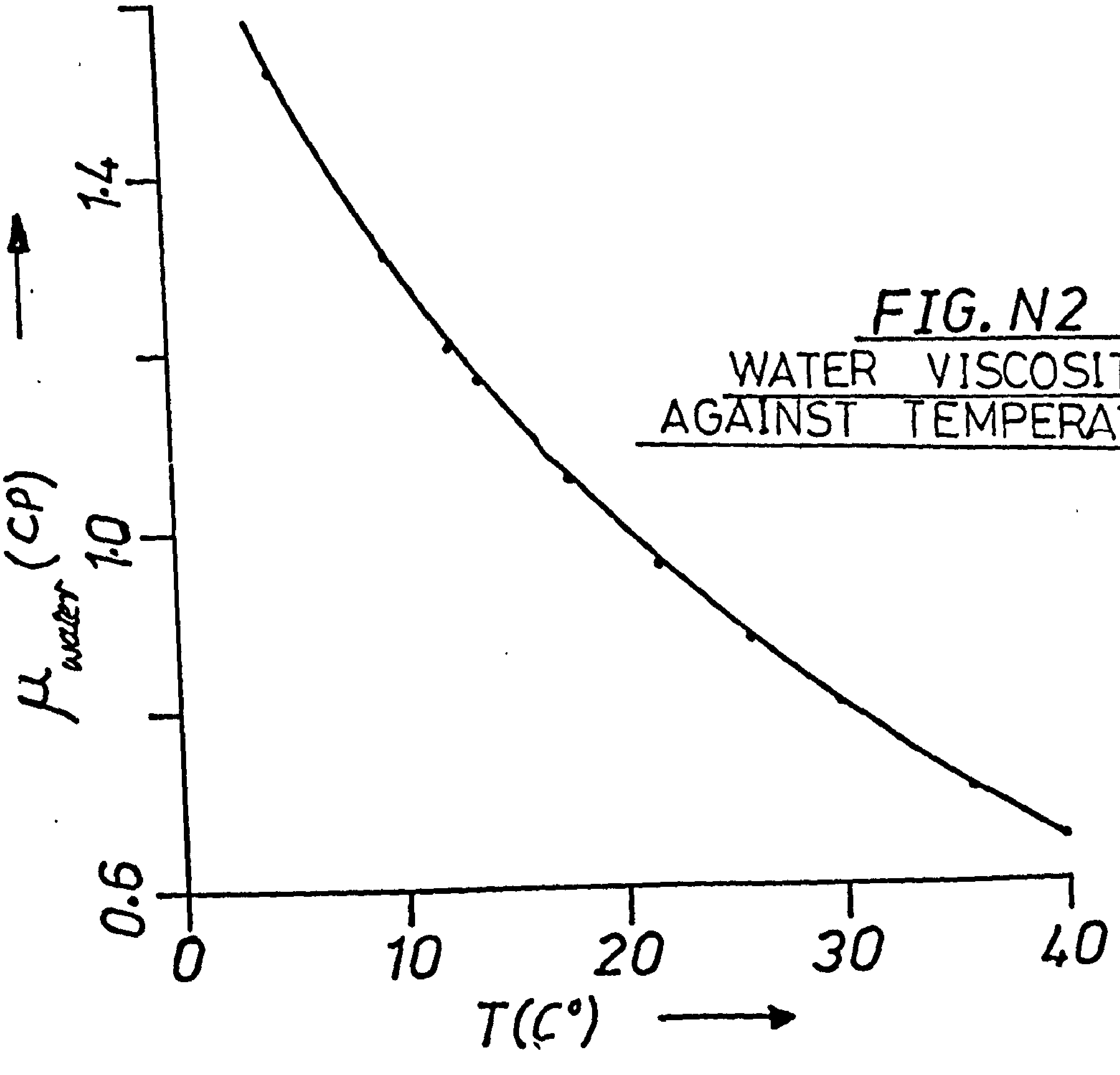


FIG. N2

WATER VISCOSITY AGAINST TEMPERATURE

2. Water Properties:*

Figs. N2, N3 and N4 show the dependence of viscosity, density and surface tension, respectively on temperature. The appropriate equations are:

$$\text{(i)} \quad 10^{-3}\mu_f = f(t)\ \frac{NS}{m^2} = \sum_{n=0}^{3} a_n t^n$$

where

$a_o = 1.77226$ $\quad a_1 = -0.0557784$

$a_2 = 0.001026$ $\quad a_3 = -0.0000083$

$$\text{(ii)} \quad \rho_f = f(t) = \frac{kg}{m^3} = \sum_{n=0}^{3} a_n t^n$$

where

$a_o = 999.903$ $\quad a_1 = 0.055173$

$a_2 = 0.00770233$ $\quad a_3 = 0.0000386$

$$\text{(iii)} \quad \sigma = f(t)\ \frac{dynes}{cm} = \sum_{n=0}^{1} a_n t^n$$

where

$a_o = 75.75$ $\quad a_1 = -0.152$

This program incorporated a function, 'QGR', to calculate air flow rate for rotameters and then corrected these for calibration, and for pressure and temperature at the working conditions. The programs developed later to help carry out the analysis of the data incorporated

---

[*] The data were taken from: Handbook of Chemistry and Physics, 53rd edition, 1972-1973, Editor: R.C. Weast.

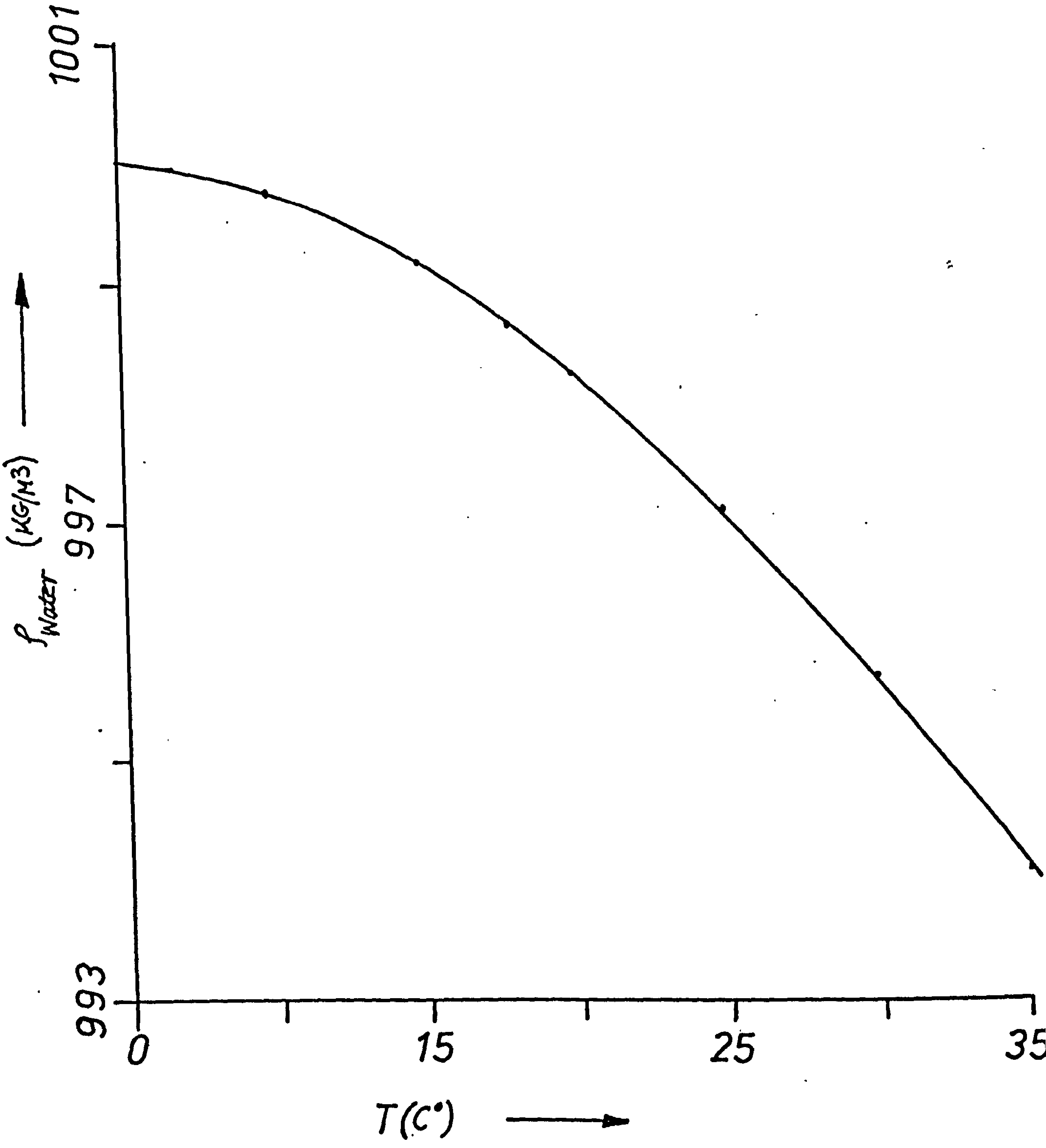


FIG. N3 WATER DENSITY AGAINST TEMPERATURE

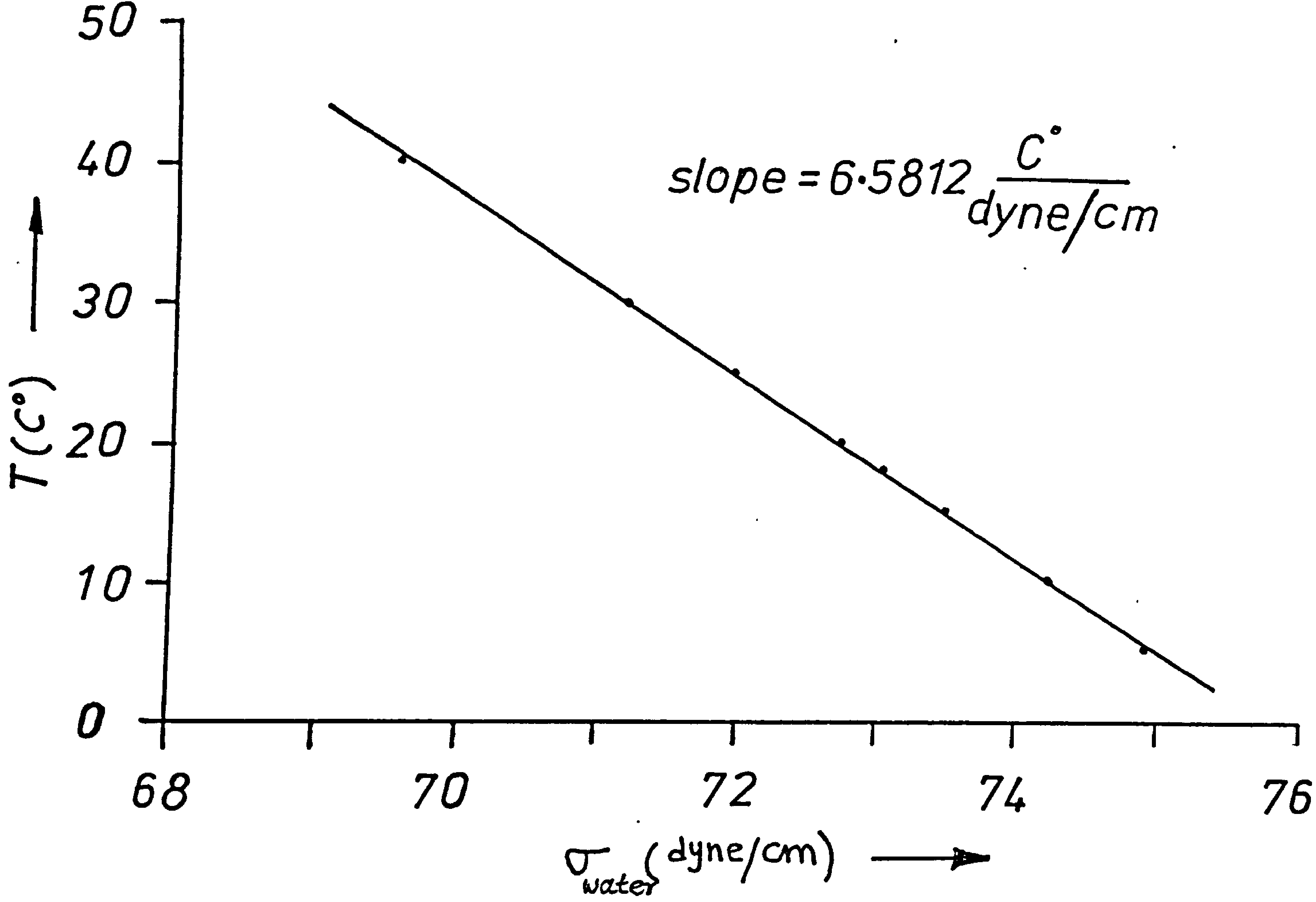


FIG. N4 WATER SURFACE TENSION AGAINST TEMPERATURE this program in the form of a subroutine labelled 'CONVERSION'. In the following, the meanings of the important variables are given followed by a listing of the program.

(a) Nomenclature:

D: pipe diameter, m

DG: Air density at pressure (p) and temperature (T) of test section conditions.

DG0: Air density at atmospheric pressure and rotameter working temperature (TG).

DG1: Air density at 1 bar gauge, 19°C.

DG2: Air density at 1 bar gauge and rotameter working temperature (TG).

DG3: Air density at rotameter working pressure (pG) and temperature (TG).

CT: Correction factor for rotameters.

M: Total number of points.

NR: Number of points taken with rotameters.

NF: Number of points taken with air orifice meter.

VD3: $\ln(I_G/I_F)$, a constant used in void fraction calculations.

FACTR: Back off potentiometer constant for void fraction calculations.

R,RR: Friction factor = $RR.Re^{-R}$

N: Test run number.

EMF: Thermocouple emf (mv)

T: Temperature at test section (°C)

HL: Head difference across water orifice (cm H_2O)

PG: Working pressure of rotameters or pressure upstream orifice (bar gauge)

S1,S2,S3,S4: Float height of each rotameter (cm)

S: Head difference across air orifice (cm H_2O)

ELE: Electrometer reading (mv)

POT: Potentiometer reading (mv)

PE: Pressure gradient (mm H_2O/m)

P: Test section pressure (mm H_2O gauge)

EL: Electrometer reading for tube full of water conditions.

PT: Potentiometer readings for tube full of water conditions.

K: Flow pattern type, i.e.

Bubble = 1
Slug = 2
Stratified = 3
Wavy = 4
Annular = 5
Plug = 6

VDF: Void fraction

DF: Water density

VF,VFF: Water viscosity

VG,VGG: Air viscosity

STN: Surface tension

TG: Air temperature upstream orifice meter

QF: Water volume flow rate

WG: Air mass flow rate

REG: Air Reynold's number

ZR: Reynold's number correction factor.

EXPC: Expansibility correction factor.

(b) Listing of the program

```
      SUBROUTINE CONVERSION
      DIMENSION TG(370)
      COMMON DG1,DG2,DG3,N(370),T(370),P(370),VDF(370),DF(370),
     1DG(370),PE(370),QF(370),QG(370),WG(370),K(370),D,PI,AP,
     2M,STN(370),R,RR,VGG(370),VFF(370)
      READ(5,316)M,NR,D,VD3,FACTR,R,RR
316   FORMAT(2I0,5F0.0)
      WRITE(6,318)M,NR,D,VD3,FACTR,R,RR
318   FORMAT(1H1,////,4X,2I10,5F10.6,////)
      PI=3.14159265
      AP=(PI/4)*D**2
      H1=((101325.+100000.)/(13550.*9.807))*100.
      H0=(101325./(13550.*9.807))*100.
      DG1=1.293*(H1/76.)/(1.+.00367*19.)
      NF=M-NR
      WRITE(6,410)
      WRITE(6,413)
413   FORMAT(4X,2HNO,4X,3HEMF,3X,4HTEMP,4X,2HHL,5X,2HPG,4X,
     12HS1,4X,2HS2,4X,2HS3,4X,2HS4,4X,3HELE,4X,3HPOT,5X,2HPE,
     26X,4HPRES,4X,2HEL,5X,2HPT,4X,5HPATRN)
      WRITE(6,414)
414   FORMAT(10X,2HMV,6X,1HC,3X,5HCMH2O,4X,3HBAR,3X,2HCM,4X,2HCM,
     14X,2HCM,4X,2HCM,18X,7HMMH2O/M,4X,5HMMH2O)
      DO 301 I=1,M
      IF(I.GT.NR)GO TO 302
      READ(5,303)N(I),EMF,T(I),HL,PG,S1,S2,S3,S4,ELE,POT,
     1PE(I),P(I),EL,PT,K(I)
303   FORMAT(I0,14F0.0,I0)
      WRITE(6,304)N(I),EMF,T(I),HL,PG,S1,S2,S3,S4,ELE,POT,
     1PE(I),P(I),EL,PT,K(I)
304   FORMAT(I8,F7.3,F6.1,F8.1,F6.2,4F6.1,F7.1,F7.2,F9.2,
     1F8.2,F7.1,F7.2,I6)
      GO TO 307
302   READ(5,305)N(I),EMF,T(I),HL,PG,S,ELE,POT,
     1PE(I),P(I),EL,PT,K(I)
305   FORMAT(I0,11F0.0,I0)
      WRITE(6,306)N(I),EMF,T(I),HL,PG,S,ELE,POT,PE(I),P(I),EL,PT,K(I)
306   FORMAT(I8,F7.3,F6.1,F8.1,F6.2,F24.1,F7.1,F7.2,F9.2,F8.2,
     1F7.1,F8.2,I6)
307   VD1=ELE+FACTR*POT
      IF(VD1.EQ.0.0)GO TO 313
      VDL=EL+FACTR*PT
      VD=ALOG(VD1/VDL)
      VDF(I)=VD/VD3
      IF(D.GT.0.130)GO TO 317
      IF(K(I).EQ.3.OR.K(I).EQ.4)GO TO 315
      IF(K(I).EQ.34.OR.K(I).EQ.43)GO TO 315
      GO TO 314
```

```
315   VDF(I)=-0.00796892083 7+0.6902376155*VDF(I)+0.3472509355
     1*VDF(I)**2-0.03755343158*VDF(I)**3
      GO TO 314
313   VDF(I)=0.0
      GO TO 314
317   VDF(I)=0.0004023068891+1.360189569*VDF(I)
     1-0.7472010053*VDF(I)**2+0.6114242107*VDF(I)**3-
     20.2270207231*VDF(I)**4
314   H=P(I)/135.5+H0
      P(I)=H*13.55*1000.*9.807/100000.0
      DF(I)=999.903+.055173*T(I)-.00770233*T(I)**2+.0000386*T(I)**3
      DG(I)=1.293*(H/76.)/(1.+.00367*T(I))
      VF=1.77226-.0557784*T(I)+.001026*T(I)**2
     1-.0000083*T(I)**3
      VG=1.70744+.00612487*T(I)-.000031396*T(I)**2
      STN(I)=75.75-(5.85/38.5)*T(I)
      VF=VF/1000.
      VG=VG/100000.
      VGG(I)=VG
      VFF(I)=VF
      PE(I)=PE(I)*249.09/(2.54*10.)
      TG(I)=(24./.95)*EMF
      DG0=1.293*(H0/76.)/(1.+.00367*TG(I))
      QF(I)=(1.45/30.)*HL**.5*101.94
      QF(I)=QF(I)/3600.0
      IF(I.GT.NR)GO TO 308
      DG2=1.293*(H1/76.)/(1.+.00367*TG(I))
      H3=((101325.+PG*100000.)/(13550.*9.807))*100.
      DG3=1.293*(H3/76.)/(1.+.00367*TG(I))
      QGC=QGR(S1)+QGR(S2)+QGR(S3)+QGR(S4)
      WG(I)=QGC*DG0
      QG(I)=WG(I)/DG(I)
      GO TO 301
308   PGAB=PG*100.+101.325
      IF(S.EQ.0.0)GO TO 309
      WG(I)=1278.98*((PGAB/6.8948)/(TG(I)*1.8+492.))**.5*
     1(S/2.54)**.5*.45359
      REG=WG(I)/(.00469*.45359)
      RX=ALOG(REG)
      ZR=.9948152513+.03265792929*RX-.004168990102*RX**2
     1+.0001330225936*RX**3
      EPY=S/(2.54*PGAB/6.8948)
      EXPC=1.0-0.01458333*EPY
      WG(I)=WG(I)*ZR*EXPC/3600.0
      QG(I)=WG(I)/DG(I)
      GO TO 301
309   WG(I)=0.0
301   CONTINUE
      WRITE(6,410)
410   FORMAT(//////////)
      WRITE(6,411)
411   FORMAT(3X,2HNO,4X,4HTEMP,3X,5HPRESS,5X,2HQF,8X,2HQG,7X,2HDG,
     16X,2HDF,7X,2HWG,5X,3HVDF,9X,2HPE,4X,6HPATERN)
      WRITE(6,412)
412   FORMAT(11X,1HC,4X,5HKN/M2,5X,6HM3/SEC,3X,6HM3/SEC,3X,5HKG/M3,
     13X,5HKG/M3,4X,6HKG/SEC,17X,4HN/M3)
```

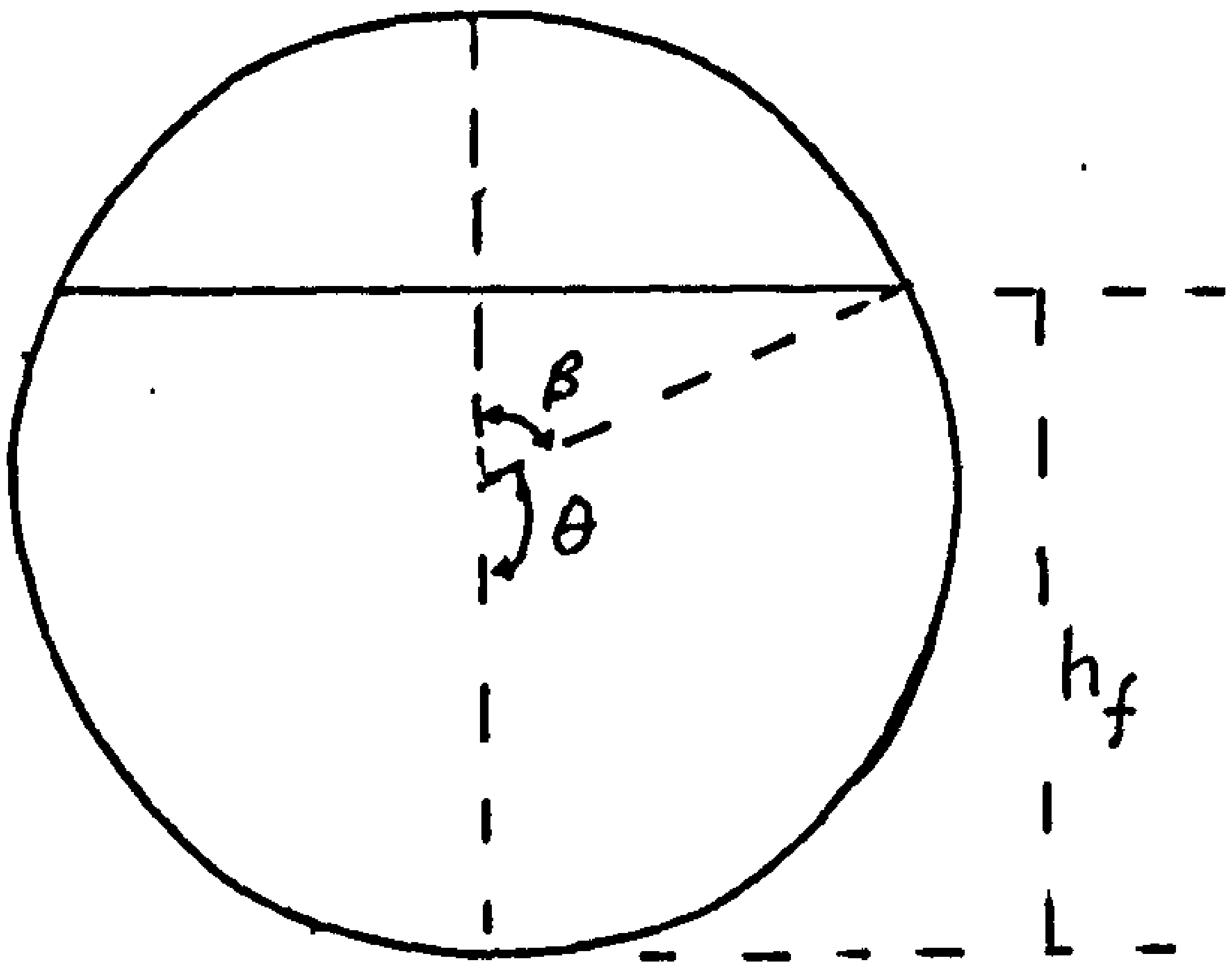
```
      DO 310 I=1,M
      WRITE(6,311)N(I),T(I),P(I),QF(I),QG(I),DG(I),DF(I),
     1WG(I),VDF(I),PE(I),K(I)
311   FORMAT(I8,F6.1,F8.2,2F10.6,F8.4,F8.3,F9.5,F6.3,F13.4,I8)
310   CONTINUE
      WRITE(6,410)
      RETURN
      END
      FUNCTION QGR(S)
      COMMON DG1,DG2,DG3,N(370),T(370),P(370),VDF(370),
     1DF(370),DG(370),PE(370),QF(370),QG(370),WG(370),K(370),
     2D,PI,AP,M,STN(370),R,RR,VGG(370),VFF(370)
      Q=69.79848882+20.23981018*S+0.0253036929*S**2
     1+0.01238440072*S**3-0.0002735459412*S**4
      CT=((DG3*DG1)**.5)/DG2
      QGR=Q*CT/60000.0
      QGR=QGR*(3.4/3.75)+.0007013
      IF(S.EQ.0.0)QGR=0.0
      RETURN
      END
```

APPENDIX P DUKLER AND TAITEL MODEL

APPENDIX P DUKLER AND TAITEL MODEL

P.1 GEOMETRICAL CONSIDERATIONS

From the figure



$$\cos\beta = \frac{x}{D/2} = \frac{h_f - D/2}{D/2}$$

$$\therefore \cos\beta = 2\tilde{h}_f - 1$$

$$\sin\beta = \sqrt{1-(2\tilde{h}_f-1)^2}$$

$$\tilde{h}_f = \frac{h_f}{D/2}$$

$$\theta = \pi - \beta = \pi - \cos^{-1}(2\tilde{h}_f-1)$$

$$A_f = \frac{2\theta}{2\pi}\left(\frac{\pi}{4}D^2\right) + 2\left[\tfrac{1}{2}(D/2)\sin\beta - (D/2)\cos\beta\right]$$

$$= \frac{\theta}{4}D^2 + \frac{D^2}{4}(2\tilde{h}_f-1)\sqrt{1-(2\tilde{h}_f-1)^2}$$

$$\therefore \tilde{A}_f = \frac{A_f}{D^2} = \frac{1}{4}\left[\pi - \cos^{-1}(2\tilde{h}_f-1) + (2\tilde{h}_f-1)\sqrt{1-(2\tilde{h}_f-1)^2}\right] \qquad \text{(P1)}$$

$$\tilde{A}_g = \frac{A_g}{D^2} = \frac{1}{4}\left[\cos^{-1}(2\tilde{h}_f-1) + (2\tilde{h}_f-1)\sqrt{1-(2\tilde{h}_f-1)^2}\right] \qquad \text{(P2)}$$

$$\tilde{S}_f = \frac{S_f}{D} = \frac{\pi D}{D}\cdot\frac{2\theta}{2\pi} = \pi - \cos^{-1}(2\tilde{h}_f-1) \qquad \text{(P3)}$$

$$\tilde{S}_i = \frac{S_i}{D} = \left(\frac{2}{D}\right)\left(\frac{D}{2}\right)\sin\beta = \sqrt{1-(2\tilde{h}_f-1)^2} \qquad \text{(P4)}$$

$$\tilde{S}_g = \frac{S_g}{D} = \cos^{-1}(2\tilde{h}_f-1) \qquad \text{(P5)}$$

P.2 THE MODEL

Momentum balance in the liquid phase

$$- A_f \left(\frac{dP}{dZ}\right) - \tau_{wf} S_f + \tau_i S_i = 0$$

or

$$\left(\frac{dP}{dZ}\right) = - \tau_{wf} \frac{S_f}{A_f} + \tau_i \frac{S_i}{A_f} \qquad \text{(P6)}$$

and in the gas phase

$$- A_g \left(\frac{dP}{dZ}\right) - \tau_{wg} S_g - \tau_i S_i = 0$$

or

$$\left(\frac{dP}{dZ}\right) = - \tau_{wg} \frac{S_g}{A_g} - \tau_i \frac{S_i}{A_g} \qquad \text{(P7)}$$

Subtracting eq. (P7) from eq. (P6) gives

$$\tau_{wg} \frac{S_g}{A_g} - \tau_{wf} \frac{S_f}{A_f} + \tau_i S_i \left(\frac{1}{A_f} - \frac{1}{A_g}\right) = 0 \qquad \text{(P8)}$$

P.3 SOLUTION

Let us assume that

$$\tau_{wf} = f_f \frac{\rho_f U_f^2}{2} \quad , \quad \tau_{wg} = f_g \frac{\rho_g U_g^2}{2} \quad , \quad \tau_i = f_i \frac{\rho_g (U_g - U_f)^2}{2} \qquad \text{(P9)}$$

also $U_f << U_g$, hence $\tau_i \simeq f_i \frac{\rho_g U_g^2}{2}$

substitute in eq. (P8)

$$-f_f \frac{\rho_f}{2} \frac{S_f}{A_f} U_f^2 + f_g \frac{\rho_g}{2} U_g^2 \left[\frac{S_g}{A_g} + \frac{f_i}{f_g}\left(\frac{S_i}{A_f} + \frac{S_i}{A_g}\right) \right] = 0$$

defining the non-dimensional parameters,

$$\tilde{U}_f = \frac{U_f}{U_{sg}} \quad , \quad \tilde{U}_g = \frac{U_g}{U_{sg}}$$

$$\therefore - f_f \frac{\rho_f}{2} \frac{\tilde{S}_f}{\tilde{A}_f} \frac{1}{D} U_{sf}^2 \tilde{U}_f^2 + f_g \frac{\rho_g}{2} U_{sg}^2 \tilde{U}_g^2 \frac{1}{D} \frac{\tilde{S}_g}{\tilde{A}_g} + \frac{f_i}{f_g} \left(\frac{S_i}{A_f} + \frac{S_i}{A_g}\right) = 0$$

factorising $f_g \frac{\rho_g}{2} \frac{U_{sg}^2}{D}$,

$$\therefore - \frac{f_f}{f_g} \left(\frac{\rho_f U_{sf}}{\rho_g U_{sg}^2}\right) \frac{\tilde{S}_f}{\tilde{A}_f} \tilde{U}_f^2 + \frac{\tilde{S}_g}{\tilde{A}_g} + \frac{f_i}{f_g} \left(\frac{\tilde{S}_i}{\tilde{A}_f} + \frac{\tilde{S}_i}{\tilde{A}_g}\right) = 0 \qquad (P10)$$

but since $\left(\frac{dP}{dZ}\right)_{sf} = \frac{4f_{sf}}{D} \left(\frac{1}{2} \rho_f U_{sf}^2\right)$, $\left(\frac{dP}{dZ}\right)_{sg} = \frac{4f_{sg}}{D} \left(\frac{1}{2} \rho_g U_{sg}^2\right)$

and $X^2 = \frac{(dP/dZ)_{sf}}{(dP/dZ)_{sg}}$

then from eq. (P10) after rearranging

$$X^2 = \frac{\frac{f_g}{f_{sg}} \frac{\tilde{S}_g}{\tilde{A}_g} + \frac{f_i}{f_g} \left(\frac{\tilde{S}_i}{\tilde{A}_f} + \frac{\tilde{S}_i}{\tilde{A}_g}\right)}{\frac{f_f}{f_{sf}} \frac{S_f}{A_f}} \tilde{U}_g^2 \qquad (P11)$$

but since

$f_f = C_f \, Re_f^{-m}$ $\qquad$ $f_g = C_g \, Re_g^{-m}$

$f_{sf} = C_f \, Re_{sf}^{-m}$ $\qquad$ $f_{sg} = C_g \, Re_{sg}^{-m}$

$$\therefore \quad \frac{f_f}{f_{sf}} = \left(\frac{D_f\ U_f}{D\ U_{sf}}\right)^{-m} = (\tilde{D}_f\ \tilde{U}_f)^{-m}$$

also

$$\frac{f_g}{f_{sg}} = (\tilde{D}_g\ \tilde{U}_g)^{-m}$$

eq. (P11) then becomes

$$X^2 = \frac{(\tilde{U}_g\ \tilde{D}_g)^{-m}\left[\frac{\tilde{S}_g}{\tilde{A}_g} + \frac{f_i}{f_g}\left(\frac{\tilde{S}_i}{\tilde{A}_f} + \frac{\tilde{S}_i}{\tilde{A}_g}\right)\right]}{(\tilde{U}_f\ \tilde{D}_f)^{-m}\ \frac{\tilde{S}_f}{\tilde{A}_f}} \qquad \text{(P12)}$$

$$\text{where} \quad D_g = \frac{4A_g}{S_g + S_i}, \quad \tilde{D}_g = \frac{4\tilde{A}_g}{\tilde{S}_g + \tilde{S}_i} \qquad \text{(P13)}$$

$$D_f = \frac{4A_f}{S_f}, \quad \tilde{D}_f = \frac{4\tilde{A}_f}{\tilde{S}_f}$$

From eqs. (P7) and (P9)

$$-\left(\frac{dP}{dZ}\right) = f_g\ \left(\tfrac{1}{2}\ \rho_g\ U_g^2\right) \frac{1}{A_g}\ \left(S_g + \frac{f_i}{f_g}\ S_i\right)$$

$$= f_g\ \left(\tfrac{1}{2}\ \rho_g\ U_{sg}^2\right) \frac{\tilde{U}_g^2}{\tilde{A}_g}\ \frac{1}{D}\ \left(\tilde{S}_g + \frac{f_i}{f_g}\ \tilde{S}_i\right) \qquad \text{(P14)}$$

or

$$-\left(\frac{dP}{dZ}\right) = \frac{1}{4}\ \frac{f_g}{f_{sg}}\ \left(-\ \frac{dP}{dZ}\right)_{sg}\ \frac{\tilde{U}_g^2}{\tilde{A}_g}\ \left(\tilde{S}_g + \frac{f_i}{f_g}\ \tilde{S}_i\right)$$

and since

$$\frac{f_g}{f_{sg}} = (\tilde{D}_g\ \tilde{U}_g)^{-m} \quad \text{and} \quad \phi_{g_o}^2 = \frac{\left(\frac{dP}{dZ}\right)}{\left(\frac{dP}{dZ}\right)_{sg}}$$

$$\therefore \quad \phi^2_{g_o} = \tfrac{1}{4}\,(\tilde{U}_g\,\tilde{D}_g)^{-m}\,\frac{U_g^2}{A_g}\,\left(\tilde{S}_g + \frac{f_i}{f_g}\,\tilde{S}_i\right) \qquad \text{(P15)}$$

From eqs. (P6) and (P9)

$$-\left(\frac{dP}{dZ}\right) = f_f\,\left(\tfrac{1}{2}\,\rho_f\,U_f^2\right)\frac{S_f}{A_f} - f_i\,\left(\tfrac{1}{2}\,\rho_g\,U_g^2\right)\frac{S_i}{A_g}$$

$$= \tfrac{1}{4}\,\frac{f_f}{f_{sf}}\,\left(-\,\frac{dP}{dZ}\right)_{sf}\,\tilde{U}_f^2\,\frac{\tilde{S}_f}{\tilde{A}_f} - \tfrac{1}{4}\,\frac{f_i}{f_{sg}}\,\left(-\,\frac{dP}{dZ}\right)_{sg}\,\tilde{U}_g^2\,\frac{\tilde{S}_i}{\tilde{A}_f}$$

or

$$\phi^2_{f_o} = \tfrac{1}{4}\,\frac{\tilde{U}_f^2}{A_f}\left[(\tilde{U}_f\tilde{D}_f)^{-m}\,\tilde{S}_f - \frac{1}{X^2}\,(\tilde{U}_g\tilde{D}_g)^{-m}\,\frac{\tilde{A}_f^2}{\tilde{A}_g^2}\,\tilde{S}_i\right] \qquad \text{(P16)}$$

substituting for X^2 from eq. (P11) we get,

$$\phi^2_{f_o} = \frac{\tilde{S}_f}{4}\,\frac{\tilde{U}_f}{\tilde{A}_f}\,(\tilde{U}_f\,\tilde{D}_f)^{-m}\left[1 - \frac{\tilde{S}_i}{\dfrac{\tilde{S}_g}{\tilde{A}_g} + \dfrac{f_i}{f_g}\left(\dfrac{\tilde{S}_i}{\tilde{A}_f} + \dfrac{\tilde{S}_i}{\tilde{A}_g}\right)}\right] \qquad \text{(P17)}$$

Equations (P12), (P15) and (P17) are the results of the model. For most stratified flows, $U_f \lesseqgtr U_g$ and in what follows the model is solved without imposing any restrictions on U_f.

From eqs. (P6) and (P9),

$$-\left(\frac{dP}{dZ}\right) = \overbrace{f_f\left(\tfrac{1}{2}\,\rho_f U_f^2\right)\frac{S_f}{A_f}}^{A} - \overbrace{f_i\left(\tfrac{1}{2}\,\rho_g U_g^2\right)\frac{S_i}{A_f}}^{B} - \overbrace{f_i\left(\tfrac{1}{2}\,\rho_g U_f^2\right)\frac{S_i}{A_f}}^{C}$$

$$+ \underbrace{2f_i\left(\tfrac{1}{2}\,\rho_g U_g^2\right)\left(\frac{U_f}{U_g}\right)\frac{S_i}{A_f}}_{D} \qquad \text{(P18)}$$

From continuity

$$\frac{U_{sf}}{U_{sg}} = \frac{A_f}{A_g}\frac{U_f}{U_g}$$

also

$$X^2 = \frac{f_{sf}}{f_{sg}} \left(\frac{\rho_f}{\rho_g}\right)\left(\frac{U_{sf}}{U_{sg}}\right)^2 \qquad \text{(P19)}$$

term A

$$= \frac{1}{4}\frac{f_f}{f_{sf}} \frac{4f_{sf}\ \rho_f\ U_{sf}^2}{2D} \tilde{U}_f^2 \frac{\tilde{S}_f}{\tilde{A}_f} = \frac{1}{4}\frac{f_f}{f_{sf}} \left(-\frac{dP}{dZ}\right)_{sf} U_f^2 \frac{S_f}{A_f}$$

term B

$$= -\frac{f_i}{4f_{sg}} \frac{4f_{sg}\ \rho_g\ U_{sg}^2}{2D} U_g^2 \frac{\tilde{S}_i}{\tilde{A}_f} = -\frac{1}{4}\frac{f_i}{f_{sg}} \left(-\frac{dP}{dZ}\right)_{sg} \tilde{U}_g^2 \frac{\tilde{S}_i}{\tilde{A}_f}$$

term C

$$= -f_i \left(\frac{1}{2}\rho_g U_f^2\right) \frac{S_i}{A_f} = -\frac{1}{4}\frac{f_i}{f_{sg}} \left(-\frac{dP}{dZ}\right)_{sg} \frac{\tilde{S}_i}{\tilde{A}_f} \tilde{U}_f^2 \left(\frac{U_{sf}}{U_{sg}}\right)^2$$

term D

$$= 2 f_i\left(\frac{1}{2}\rho_g U_g^2\right) \frac{U_f}{U_g} \frac{S_i}{A_f} = \frac{1}{2}\frac{f_i}{f_{sg}} \left(\frac{dP}{dZ}\right)_{sg} (\tilde{U}_g \tilde{U}_f)\left(\frac{\tilde{S}_i}{\tilde{A}_f}\right)\left(\frac{U_{sf}}{U_{sg}}\right)$$

from eq. (P19)

$$\left(\frac{U_{sf}}{U_{sg}}\right) = \left(\frac{f_{sg}}{f_{sf}}\right)^{\frac{1}{2}} \left(\frac{\rho_g}{\rho_f}\right)^{\frac{1}{2}} X$$

but

$$\left(\frac{f_{sg}}{f_{sf}}\right) = \left(\frac{U_{sg}}{U_{sf}}\right)^{-m} \left(\frac{\nu_f}{\nu_g}\right)^{-m}$$

$$\therefore \left(\frac{U_{sf}}{U_{sg}}\right) = \left(\frac{\rho_g}{\rho_f}\right)^{\frac{1}{2}} \left(\frac{\nu_f}{\nu_g}\right)^{-\frac{m}{2}} \left(\frac{U_{sg}}{U_{sf}}\right)^{-\frac{m}{2}} X$$

or

$$\left(\frac{U_{sf}}{U_{sg}}\right) = \left(\frac{\rho_g}{\rho_f}\right)^{\frac{1}{2-m}} \left(\frac{\nu_f}{\nu_g}\right)^{-\frac{m}{2-m}} X^{\frac{2-m}{2}} \qquad \text{(P20)}$$

hence at a given temperature and pressure, eq. (P20) can be written as

$$\left(\frac{U_{sf}}{U_{sg}}\right) = K\, X^{n} \qquad \text{(P20)}$$

where $n = \frac{2-m}{2}$ and $K = \left(\frac{\rho_g}{\rho_f}\right)^{\frac{1}{2-m}} \left(\frac{\nu_f}{\nu_g}\right)^{-\frac{m}{2-m}}$

substituting back in eq. (P18), we get

$$\phi^2_{f_o} = \tfrac{1}{4}\Big[(\tilde{D}_f\ \tilde{U}_f)^{-m}\,\tilde{U}_f^2\left(\frac{\tilde{S}_f}{\tilde{A}_f}\right) - (\tilde{D}_g\ \tilde{U}_g)^{-m}\,\tilde{U}_g^2\,\frac{\tilde{S}_i}{\tilde{A}_f}\,X^2$$

$$- (\tilde{D}_g\ \tilde{U}_g)^{-m}\,\tilde{U}_f^2\,\frac{\tilde{S}_i}{\tilde{A}_f}\,K^2\,X^{2n-2} + 2(\tilde{D}_g\ \tilde{U}_g)^{-m}\,\tilde{U}_g\,\tilde{U}_f$$

$$\frac{\tilde{S}_i}{\tilde{A}_f}\,K\,X^{n-2}\Big] \qquad \text{(P21)}$$

From eqs. (P7) and (P9),

$$-\left(\frac{dP}{dZ}\right) = \overbrace{f_g\left(\tfrac{1}{2}\ \ {}_{g}U_g^2\right)\frac{S_g}{A_g}}^{A} + \overbrace{f_i\left(\tfrac{1}{2}\ \ {}_{g}U_g^2\right)\frac{S_i}{A_g}}^{B} + \overbrace{f_i\left(\tfrac{1}{2}\ \ {}_{g}U_f^2\right)\frac{S_i}{A_g}}^{C}$$

$$\underbrace{-\,2f_i\left(\tfrac{1}{2}\ \ {}_{g}\ U_g\ U_f\right)\frac{S_i}{A_g}}_{D} \qquad \text{(P22)}$$

term A

$$= \tfrac{1}{4}\,\frac{f_g}{f_{sg}}\left(\frac{4f_{sg}\ \rho_g\ U_{sg}^2}{2D}\right)\tilde{U}_g^2\,\frac{\tilde{S}_g}{\tilde{A}_g} = \tfrac{1}{4}\,\frac{f_g}{f_{sg}}\left(-\,\frac{dP}{dZ}\right)_{sg}\tilde{U}_g^2\,\frac{\tilde{S}_g}{\tilde{A}_g}$$

term B

$$= \tfrac{1}{4}\,\frac{f_i}{f_{sg}}\,\left(\frac{4f_{sg}\,\rho_g\,U_{sg}^2}{2D}\right)\tilde{U}_g^2\,\frac{\tilde{S}_i}{\tilde{A}_g} = \tfrac{1}{4}\,\frac{f_i}{f_{sg}}\,\left(-\frac{dP}{dZ}\right)_{sg}\tilde{U}_g^2\,\frac{\tilde{S}_i}{\tilde{A}_g}\ .$$

term C

$$= f_i\,\tfrac{1}{2}\,\rho_g\,U_g^2\left(\frac{U_f}{U_g}\right)^2\frac{S_i}{A_g} = \tfrac{1}{4}\,\frac{f_i}{f_{sg}}\left(-\frac{dP}{dZ}\right)_{sg}\tilde{U}_f^2\left(\frac{U_{sf}}{U_{sg}}\right)^2\frac{\tilde{S}_i}{\tilde{A}_g}$$

term D

$$= -\,2f_i\left(\tfrac{1}{2}\,\rho_g\,U_g\,U_f\right)\frac{S_i}{A_g} = -\,\tfrac{1}{2}\,\frac{f_i}{f_{sg}}\left(-\frac{dP}{dZ}\right)_{sg}\tilde{U}_g\,\tilde{U}_f\left(\frac{U_{sf}}{U_{sg}}\right)\frac{\tilde{S}_i}{\tilde{A}_g}$$

substituting back in eq. (P22), we get

$$\phi^2_{g_o} = \tfrac{1}{4}\Big[(\tilde{D}_g\,\tilde{U}_g)^{-m}\,\tilde{U}_g^2\,\frac{\tilde{S}_g}{\tilde{A}_g} + (\tilde{D}_g\,\tilde{U}_g)^{-m}\,\tilde{U}_g^2\,\frac{\tilde{S}_i}{\tilde{A}_g} + (\tilde{D}_g\,\tilde{U}_g)^{-m}\,\tilde{U}_f^2\,K^2\,X^{2n}\,\frac{\tilde{S}_i}{\tilde{A}_g} - 2(\tilde{D}_g\,\tilde{U}_g)^{-m}\,\tilde{U}_g\,\tilde{U}_f\,K\,X^n\,\frac{\tilde{S}_i}{\tilde{A}_g}\Big] \qquad \text{(P23)}$$

Equations p(21) and p(23) are the predictions of the model. From eqs. (P8) and (P9),

$$f_g\left(\tfrac{1}{2}\,\rho_g U_g^2\right)\frac{S_g}{A_g} - f_f\left(\tfrac{1}{2}\,\rho_f\,U_f^2\right)\frac{S_f}{A_f} + f_i\,\tfrac{1}{2}\,\rho_g(U_g - U_f)^2\left(\frac{S_i}{A_f} + \frac{S_i}{A_g}\right) = 0$$

which reduces to

$$\tfrac{1}{4}\left(\frac{f_g}{f_{sg}}\right)\left(\frac{-dP}{dZ}\right)_{sg} \tilde{U}_g^2 \frac{\tilde{S}_g}{\tilde{A}_g} - \tfrac{1}{4}\left(\frac{f_f}{f_{sf}}\right)\left(\frac{-dP}{dZ}\right)_{sf} \tilde{U}_f^2 \frac{\tilde{S}_f}{\tilde{A}_f} +$$

$$\left(-\frac{dP}{dZ}\right)_{sg} \left(\frac{\tilde{S}_i}{\tilde{A}_g} + \frac{\tilde{S}_i}{\tilde{A}_f}\right) \left[\tfrac{1}{4}\left(\frac{f_i}{f_{sg}}\right) \tilde{U}_g^2 + \tfrac{1}{4}\left(\frac{f_i}{f_{sg}}\right) \tilde{U}_f^2 \left(\frac{U_{sf}}{U_{sg}}\right)^2 \right.$$

$$\left. - \tfrac{1}{4}\left(\frac{2f_i}{f_{sg}}\right) \tilde{U}_f^2 \left(\frac{U_{sf}}{U_{sg}}\right) \right] = 0$$

finally

$$X^2 = \left[\left(\frac{f_f}{f_{sf}}\right) \tilde{U}_f^2 \frac{\tilde{S}_f}{\tilde{A}_f}\right]^{-1} \left[\left(\frac{f_g}{f_{sg}}\right) \tilde{U}_g^2 \frac{\tilde{S}_g}{\tilde{A}_g} + \left(\frac{\tilde{S}_i}{\tilde{A}_g} + \frac{\tilde{S}_i}{\tilde{A}_f}\right)\left(\frac{f_i}{f_{sg}}\right) \tilde{U}_g^2 \right.$$

$$\left. + \left(\frac{\tilde{S}_i}{\tilde{A}_g} + \frac{\tilde{S}_i}{\tilde{A}_f}\right)\left(\frac{f_i}{f_{sg}}\right) \tilde{U}_f^2 K^2 X^{2n} - 2\left(\frac{\tilde{S}_i}{\tilde{A}_g} + \frac{\tilde{S}_i}{\tilde{A}_f}\right)\left(\frac{f_i}{f_{sg}}\right) \tilde{U}_g \tilde{U}_f K X^n \right] \qquad \text{(P24)}$$

Equations (P24), (P23) and (P21) are the results of the exact solution.

P.4 CALCULATIONAL PROCEDURES

For both solutions mentioned above the main parameter required for the calculation is the liquid level h_f and some criteria for calculating the friction factors. For the approximate solution given by eqs (P12), (P15) and (P17) the calculational procedure is straight forward.

However, for the exact solution it is not as simple and iterative procedure using computer has to be done. The program is given later with nomenclature. The calculational procedure was

(i) The properties were calculated knowing the temperature and pressure of the system, then the term K given by eq. (P20) was calculated.

(ii) Approximate value for X^2 was calculated using eq. (P12), i.e. assuming $U_f << U_g$. Equation (P24) was written in the form

$$Y = A + B\,Y^n + C\,Y^{\frac{n}{2}} \qquad \text{(P25)}$$

where $Y = X^2$, A, B, and C are the coefficients of eq. (P24).

Substituting the approximate value of Y(i.e. X^2) in eq. (P25), a better value of Y is derived. This new value is used to calculate a better estimate and so on. The iterative procedure is termined by some convergence criteria, such as $Y_{new} - Y_{old}$ 0.001.

(iii) Knowing the values of X and h_f, the friction multipliers were then calculated using eqs. (P23) and (P21).

COMPUTER PROGRAM

NOMENCLATURE

PI	$= \pi = 3.1415926$
T	Temperature °C
H	Absolute pressure in cm Hg
FI	Interface friction factor
FG	Gas friction factor
DG, DL	Density of gas and liquid respectively
VG, VL	Viscosity of gas and liquid respectively

PT	Properties Term
AG, AL	C/s area of gas and liquid respectively
SG, SL, SI	Periferal distance gas and liquid at the wall respectively, and interfacial distance
UG, UL	Gas and liquid velocities
DGH, DLH	Hydraulic diameter gas and liquid respectively.

LISTING OF THE PROGRAM

```
      PROGRAM(MODEL)
      INPUT 5=CR0
      OUTPUT6=LP0
      TRACE 2
      COMPACT
      END
      MASTER MODEL
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON AAA,BBB,CCC,B,AB,RY,PP
      PI=ACOS(-1.0D0)
      T0=10.0
      H0=76.0
      AB=0.000000001D0
      T=T0
      H=H0
      FI=1.0D0
      FG=1.0D0
      R1=.2D0
      R2=.2D0
      RR=-R1
      NN=0
      M=26
      HLL=0.01D0
      WRITE(6,30)PI
30    FORMAT(/////F30.20,///////////)
130   JJ=0
      H=H0
40    WRITE(6,70)
70    FORMAT(1H1,4X,'P CM HG',6X,'TEMP C',7X,'ACCURACY OF X ',/)
      WRITE(6,60)H,T,AB
60    FORMAT(4X,2F10.3,F20.10,////)
      WRITE(6,50)
50    FORMAT(10X,'HL',10X,'TPMG',10X,'TPML',11X,'X2',11X,'X',
     19X,'TPMLM',9X,'TPMGM',4X,'ITERATIONS',//)
      HL=.01D0
      B=2.0D0/(2.0D0+RR)
      FF=2.0D0*B-2.0D0
      ZZ=B-2.0D0
      SS=(1.0D0+RR)/(2.0D0+RR)
```

```
C
C     START OF PROPERTIES CALCULATIONS
C
      DG=1.293*(H/76.0)/(1.0+0.00367*T)
      DL=999.903+0.055173*T-0.00770233*T**2
     1+0.0000386*T**3
      VG=1.70744+0.00612487*T-0.000031396*T**2
      VL=1.77226-0.0557784*T+0.001026*T**2
     1-0.0000083*T**3
      VL=VL/1000.0
      VG=VG/100000.0
      PT=(DG/DL)**(SS)*(VL/VG)**((RR*B)/2.0D0)
      DO 10 I=1,M
      IF(HL.GT.0.1D0.AND.HL.LT.0.9D0)HLL=0.1D0
      IF(HL.GE.0.9D0)HLL=0.01D0
      KK=0
C
C     CALCULATING THE NON-DIMENSIONAL PARAMETERS
C
      FI=3.0D0-4.0D0*(0.50D0-HL)
      F=2.0D0*HL-1.0D0
      AL=0.25D0*(PI-ACOS(F)+F*((1.0D0-F**2)**.5D0))
      AG=0.25D0*(ACOS(F)-F*((1.D0-F**2)**.5D0))
      SL=PI-ACOS(F)
      SG=ACOS(F)
      SI=(1.D0-F**2)**.5D0
      UL=(PI/4.D0)/AL
      UG=(PI/4.D0)/AG
      DGH=(4.D0*AG)/(SG+SI)
      DLH=4.D0*AL/(SL)
      HH=(DGH*UG)**RR
      TT=(DLH*UL)**RR
C
C     CALCULATING THE MARTINELLI AND TWO PHASE
C     MULTIPLIERS ASSUMING UL<<UG
C
      AA=((SG/AG)+(FI/FG)*((SI/AL)+(SI/AG)))*HH
      X2=(AA*(UG**2))/(((SL/AL)*(UL**2))*(TT))
      TPMG=((UG**2)*(SG+(FI/FG)*SI)/(4.D0*AG))*HH
      BB=SL*(TT)-((1.D0/X2)*((AL/AG)**2)*SI*HH)
      TPML=((UL**2)/(4.D0*AL))*BB
      TTT=TT*(UL**2)*(SL/AL)
      AAA=(HH/TTT)*(UG**2)*((SG/AG)+((SI/AG)+(SI/AL)))
      BBB=(HH/TTT)*((SI/AG)+(SI/AL))*((UL*PT)**2)
      CCC=2.0D0*(HH/TTT)*((SI/AG)+(SI/AL))*UG*UL*PT
C
C     CALCULATING A BETTER ESTIMATE OF MARTINELLI
C     MULTIPLIER BY ITERATION.NO RESTRICTIONS ON UL.
C
      Y0=X2
      RY0=X2**.5D0
 110  Y1=XM(Y0)
      KK=KK+1
      PP0=DABS(RY-RY0)
      IF(PP0.LE.PP)GO TO 80
      KK=KK+1
      RY1=RY
      Y2=XM(Y1)
```

```
      PP1=DABS(RY-RY1)
      IF(PP1.LE.PP)GO TO 90
      KK=KK+1
      RY2=RY
      Y00=Y0-(((Y1-Y0)**2)/(Y2-2.0*Y1+Y0))
      RY00=Y00**.5D0
      PP=AB*RY00
      PP2=DABS(RY00-RY2)
      IF(PP2.LE.PP)GO TO 100
      Y0=Y00
      GO TO 110
80    X2=Y1
      X=RY
      GO TO 120
90    X2=Y2
      X=RY
      GO TO 120
100   X2=Y00
      X=RY00
C
C     CALCULATING THE NEW TWO PHASE MULTIPLIERS.
C
120   AAL=(TT)*(SL/AL)*(UL**2)
      BBL=HH*(SI/AL)*(UG**2)*(1.0D0/X2)
      CCL=HH*(SI/AL)*(UL**2)*(PT**2)*(X**FF)
      DDL=2.0D0*HH*UG*UL*(SI/AL)*PT*(X**ZZ)
      TPMLM=0.25D0*(AAL-BBL-CCL+DDL)
      AAG=HH*(UG**2)*(SG/AG)
      BBG=HH*(UG**2)*(SI/AG)
      CCG=HH*(UL**2)*(PT**2)*(SI/AG)*(X**(2.0D0*B))
      DDG=2.0D0*HH*UG*UL*PT*(SI/AG)*(X**B)
      TPMGM=0.25D0*(AAG+BBG+CCG-DDG)
      WRITE(6,20)HL,TPMG,TPML,X2,X,TPMLM,TPMGM,KK
      HL=HL+HLL
10    CONTINUE
20    FORMAT(3F13.3,2F15.6,2F13.3,I10)
      H=H+H0
      JJ=JJ+1
      IF(JJ.LT.3)GO TO 40
      T=T+T0
      NN=NN+1
      IF(NN.LT.3)GO TO 130
      STOP
      END
      FUNCTION XM(Y)
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
      COMMON AAA,BBB,CCC,B,AB,RY,PP
      XM=AAA+BBB*(Y**B)-CCC*(Y**(B/2.0D0))
      RY=XM**.5D0
      PP=AB*RY
      RETURN
      END
      FINISH
 16.50.55-
```

APPENDIX R PRESSURE DISTRIBUTION GRAPHS FOR PHASES 1, 2 AND 3.

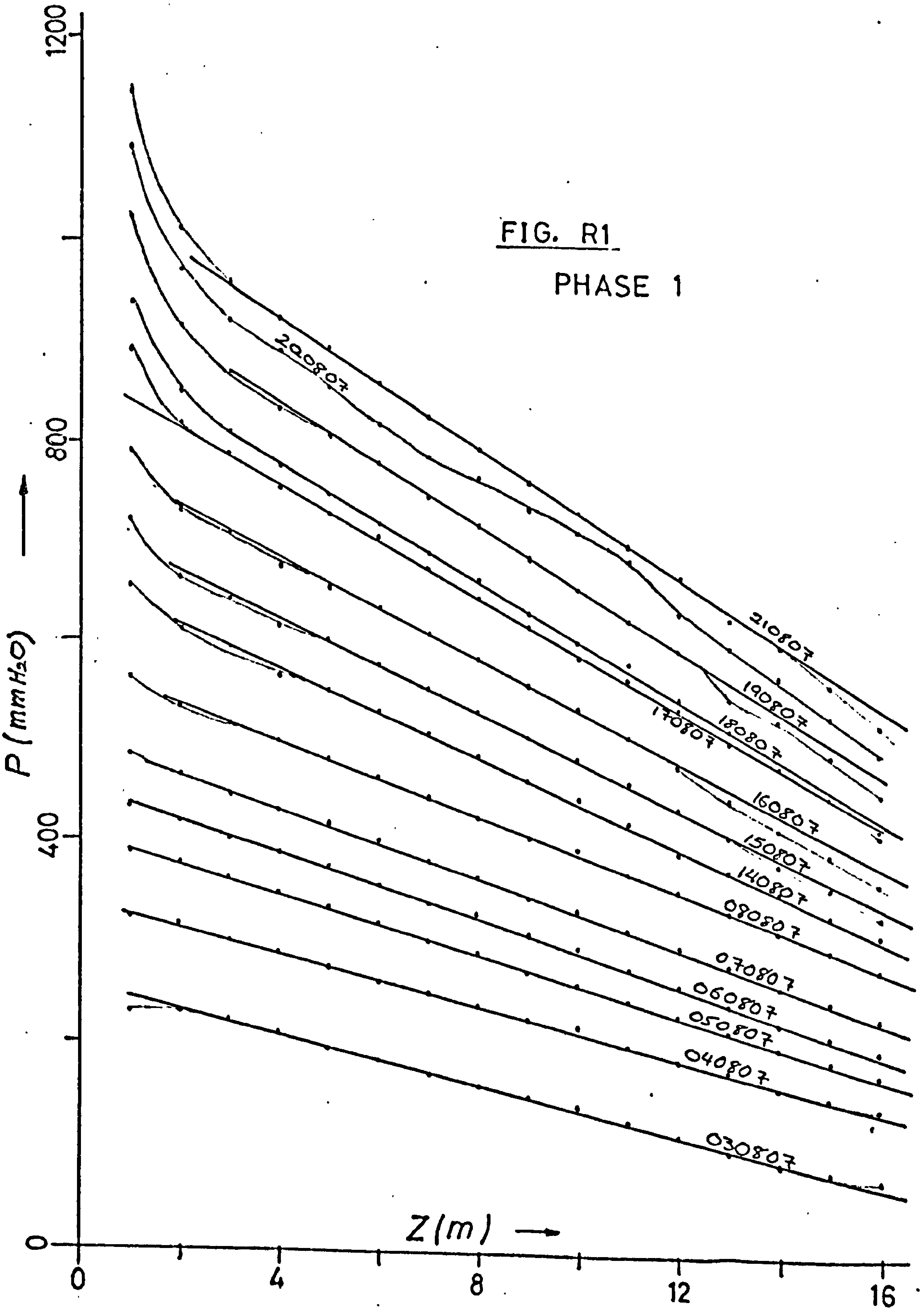


FIG. R1

PHASE 1

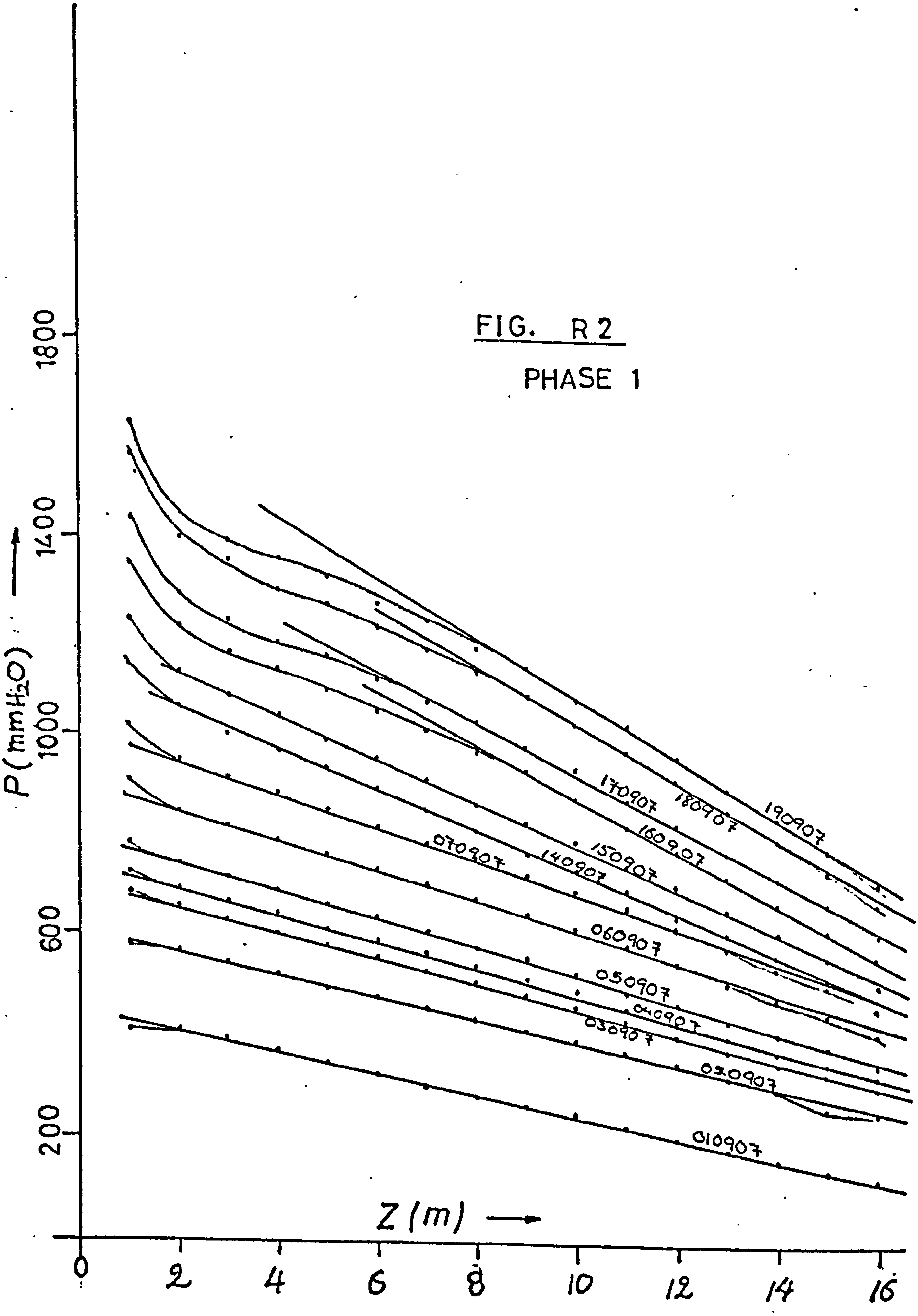


FIG. R2

PHASE 1

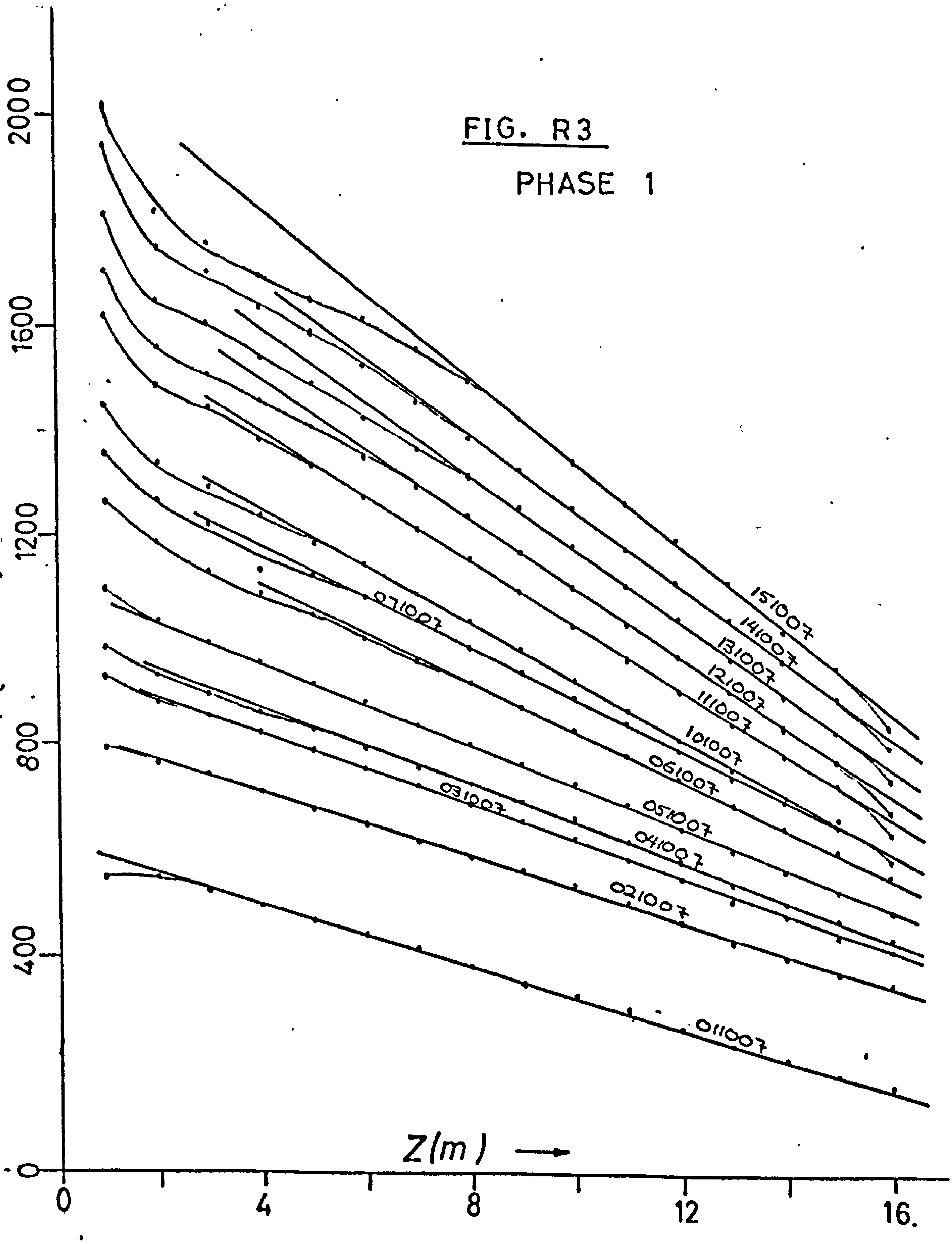


FIG. R3

PHASE 1

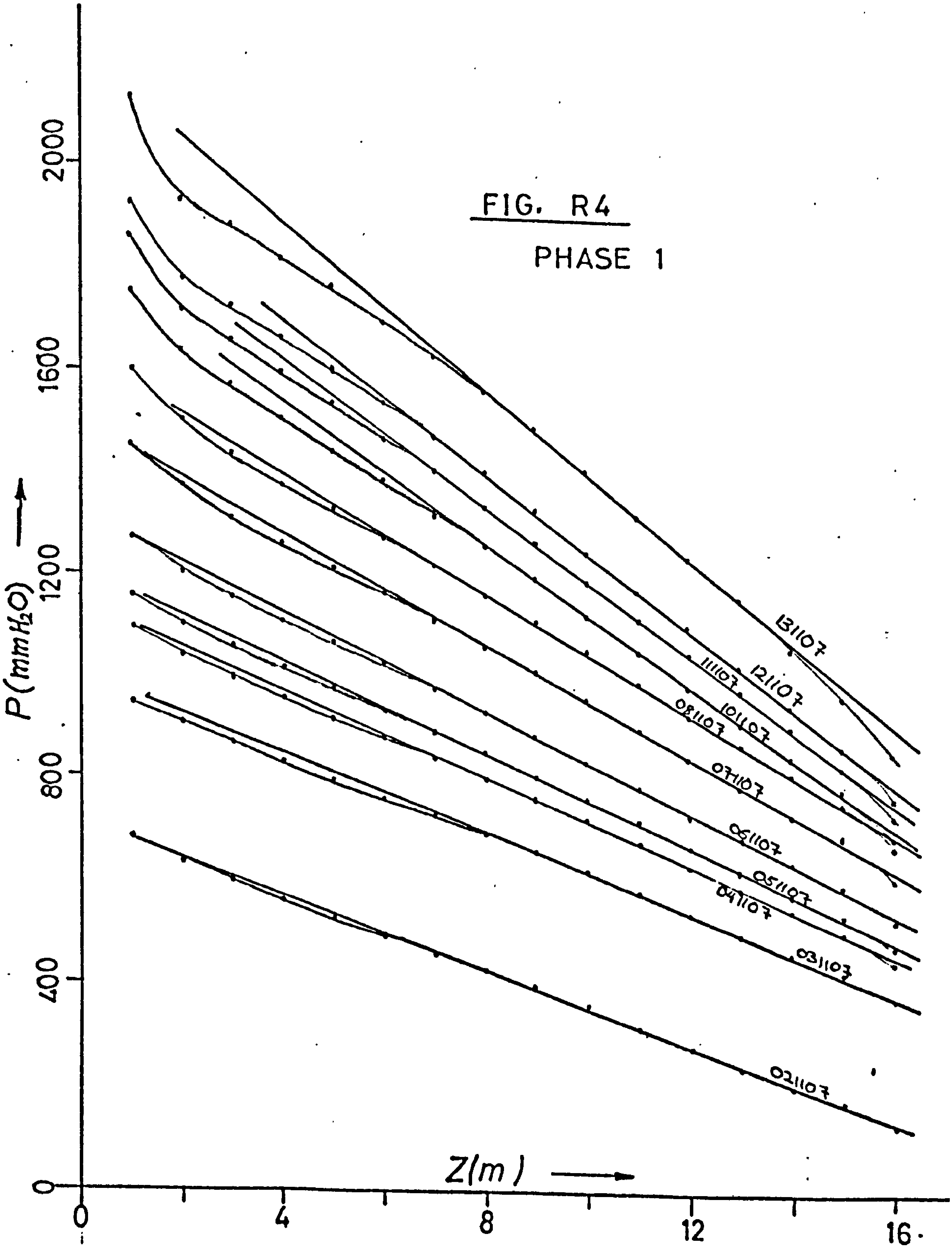


FIG. R4

PHASE 1

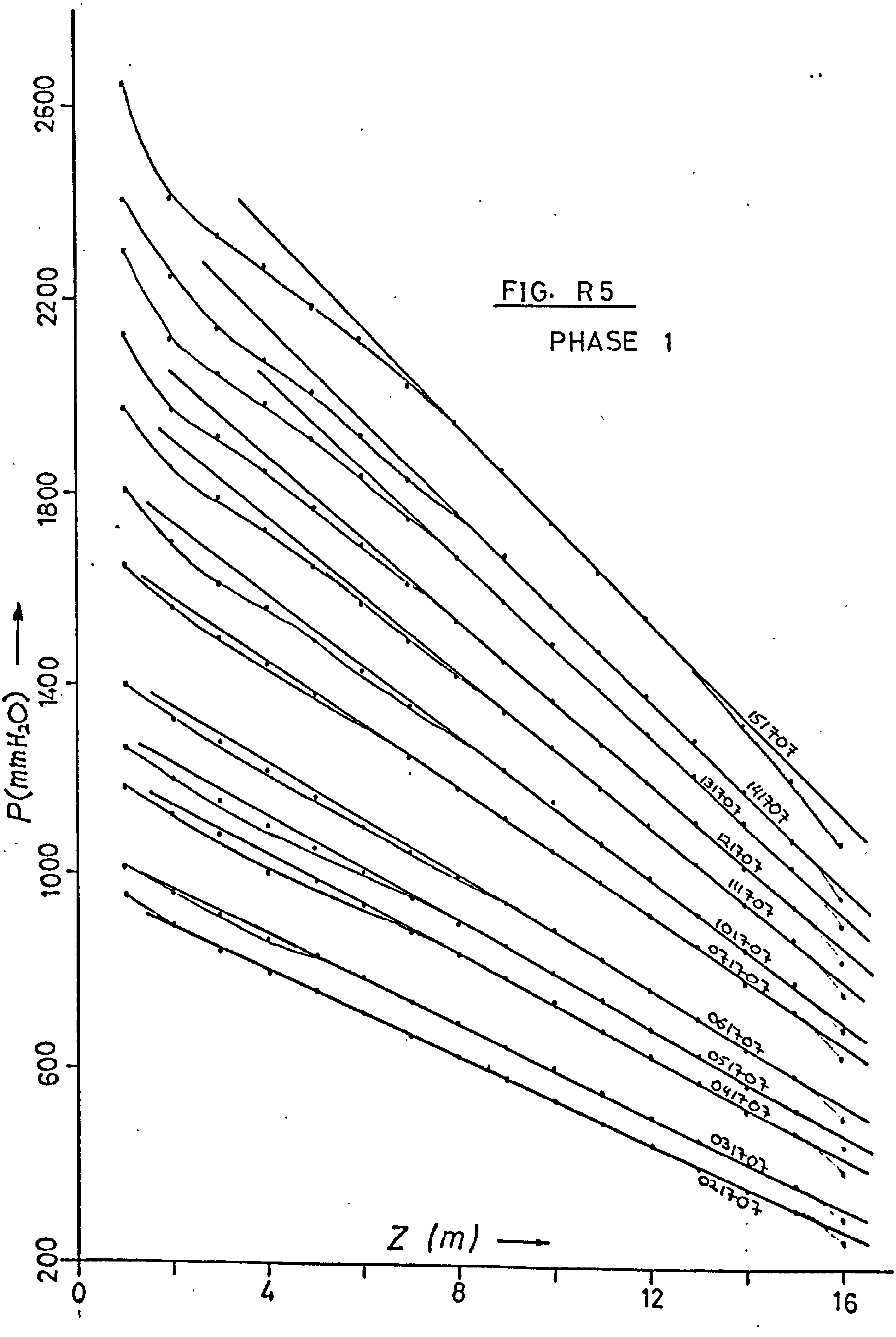


FIG. R5

PHASE 1

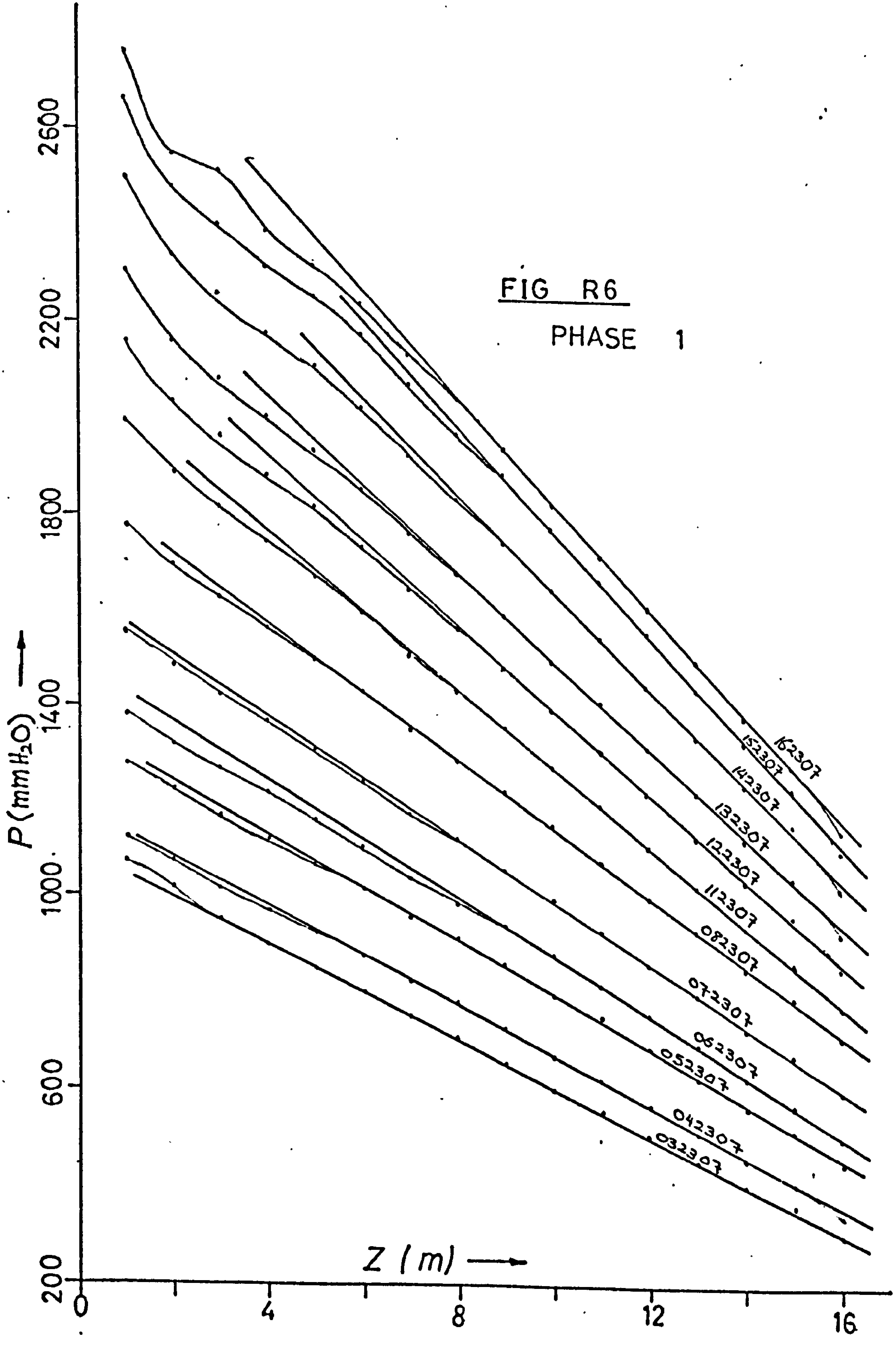


FIG R6

PHASE 1

FIG R7

PHASE 1

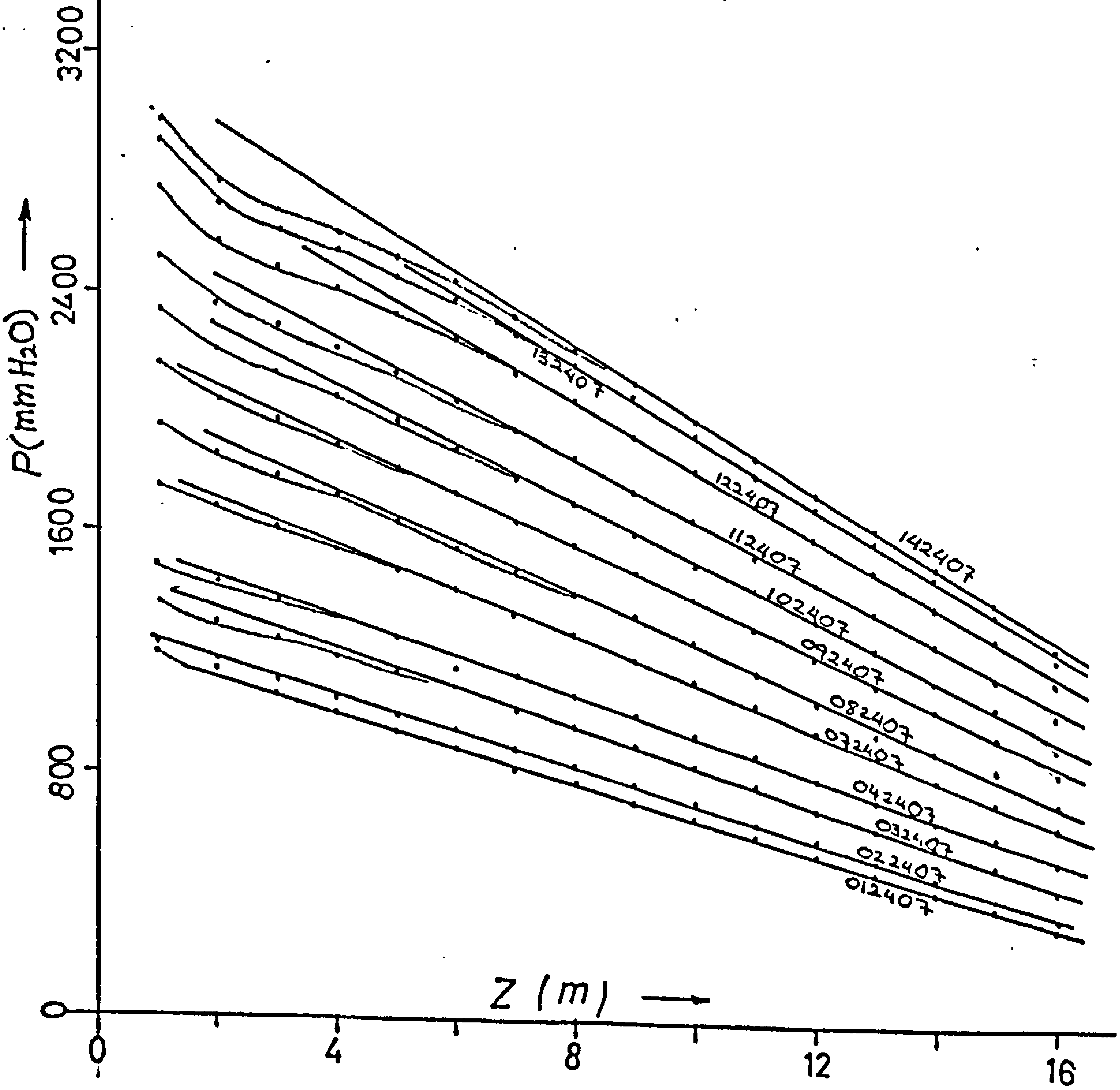
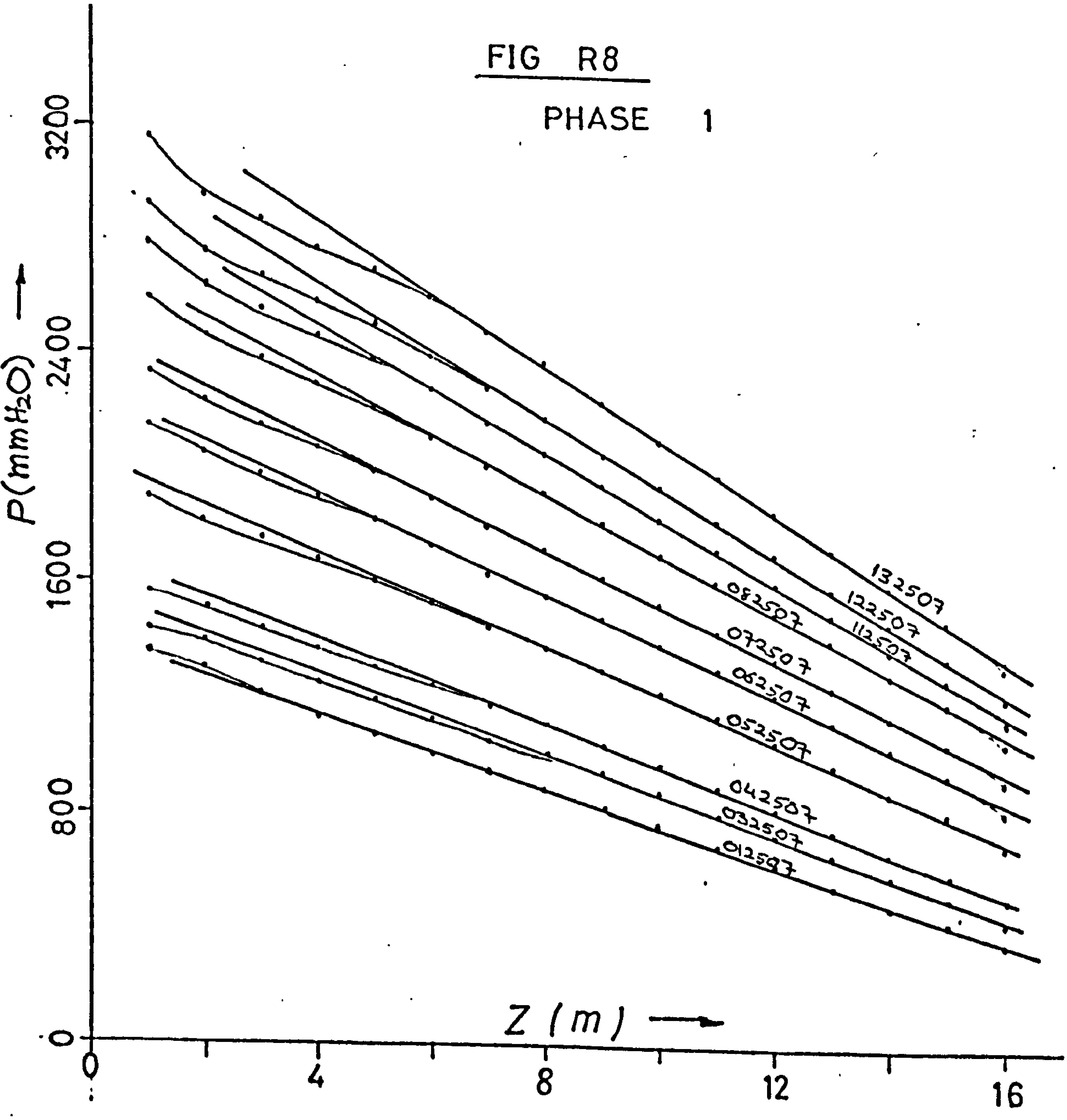


FIG R8

PHASE 1



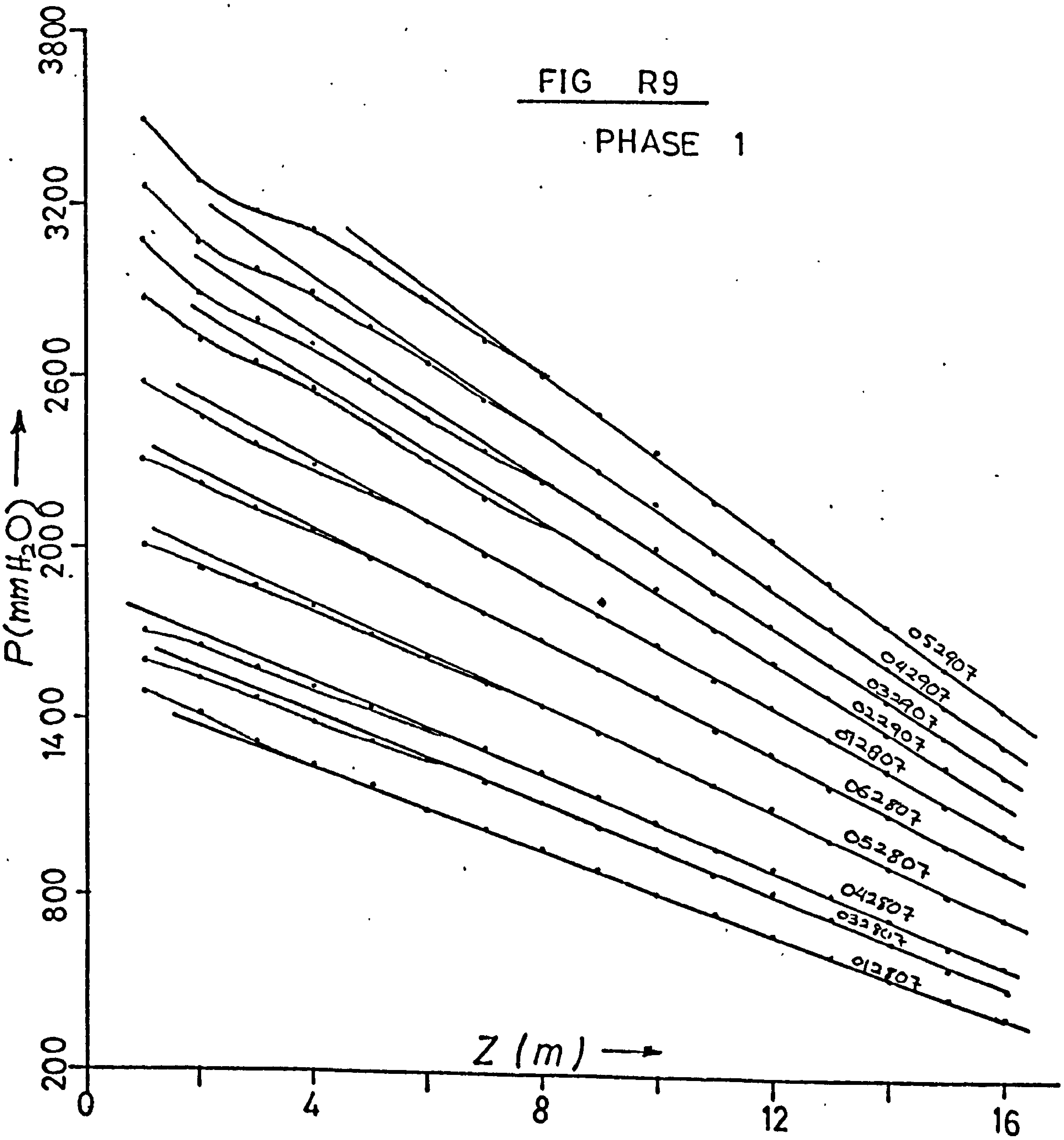


FIG R9

PHASE 1

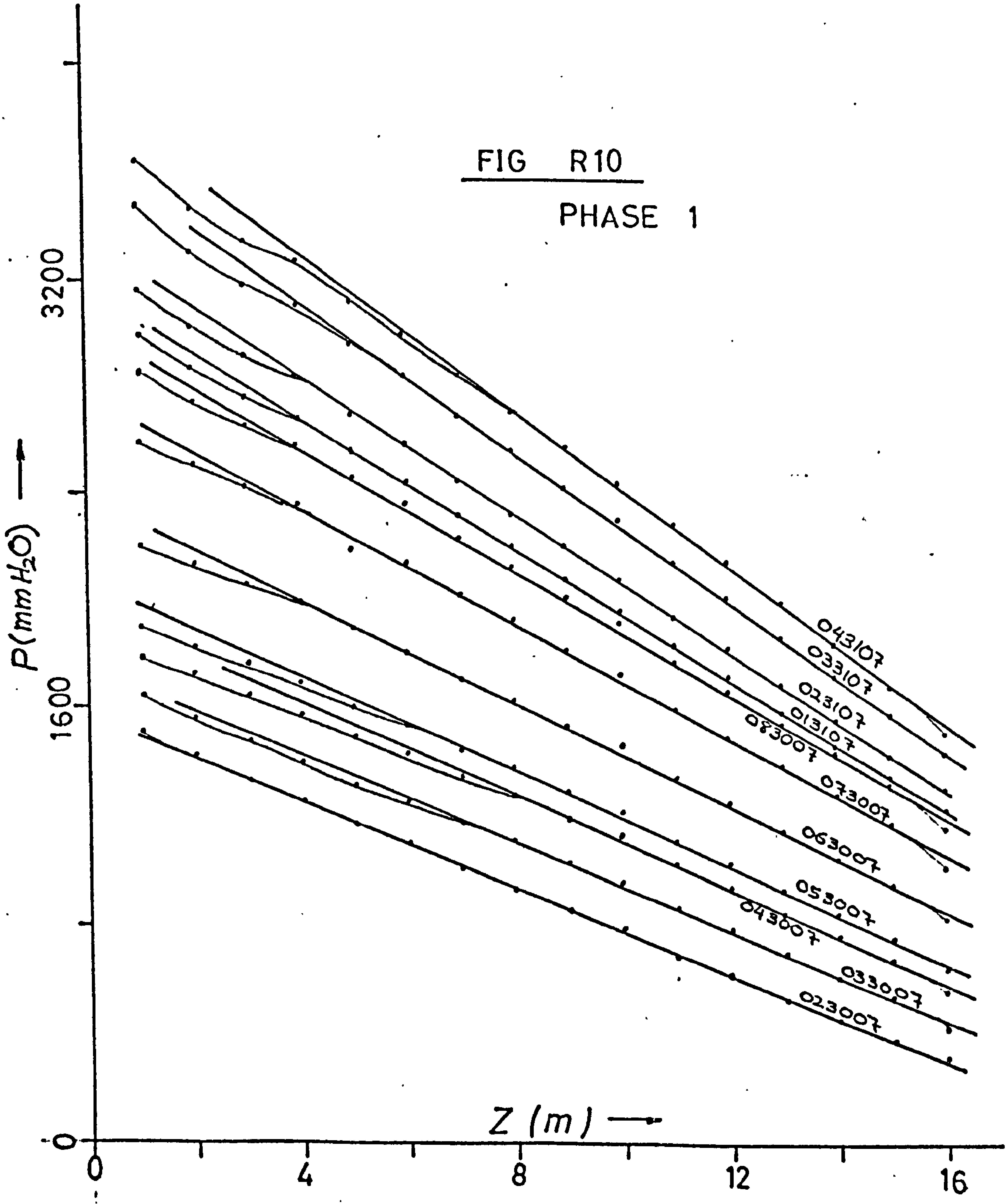


FIG R10

PHASE 1

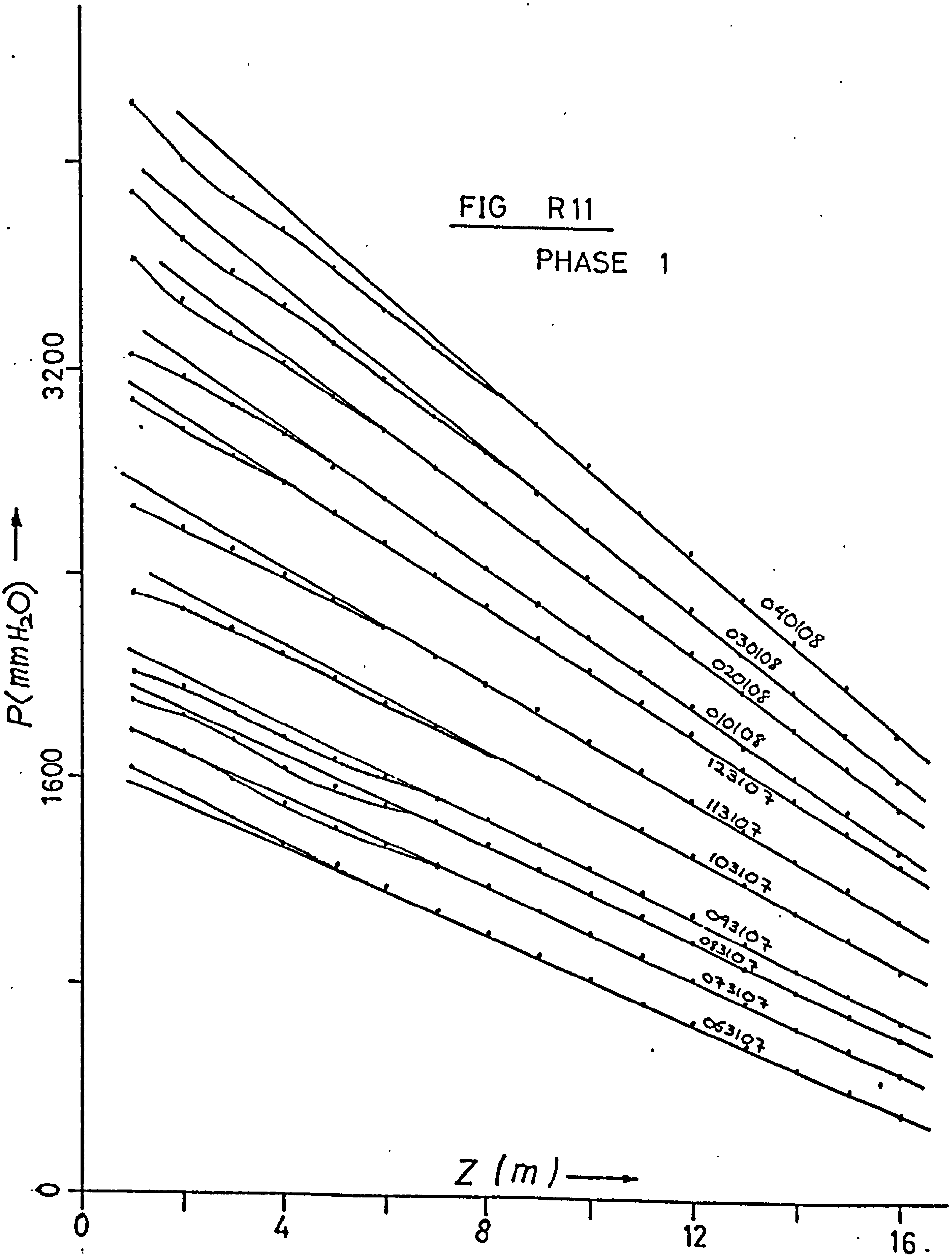


FIG R11

PHASE 1

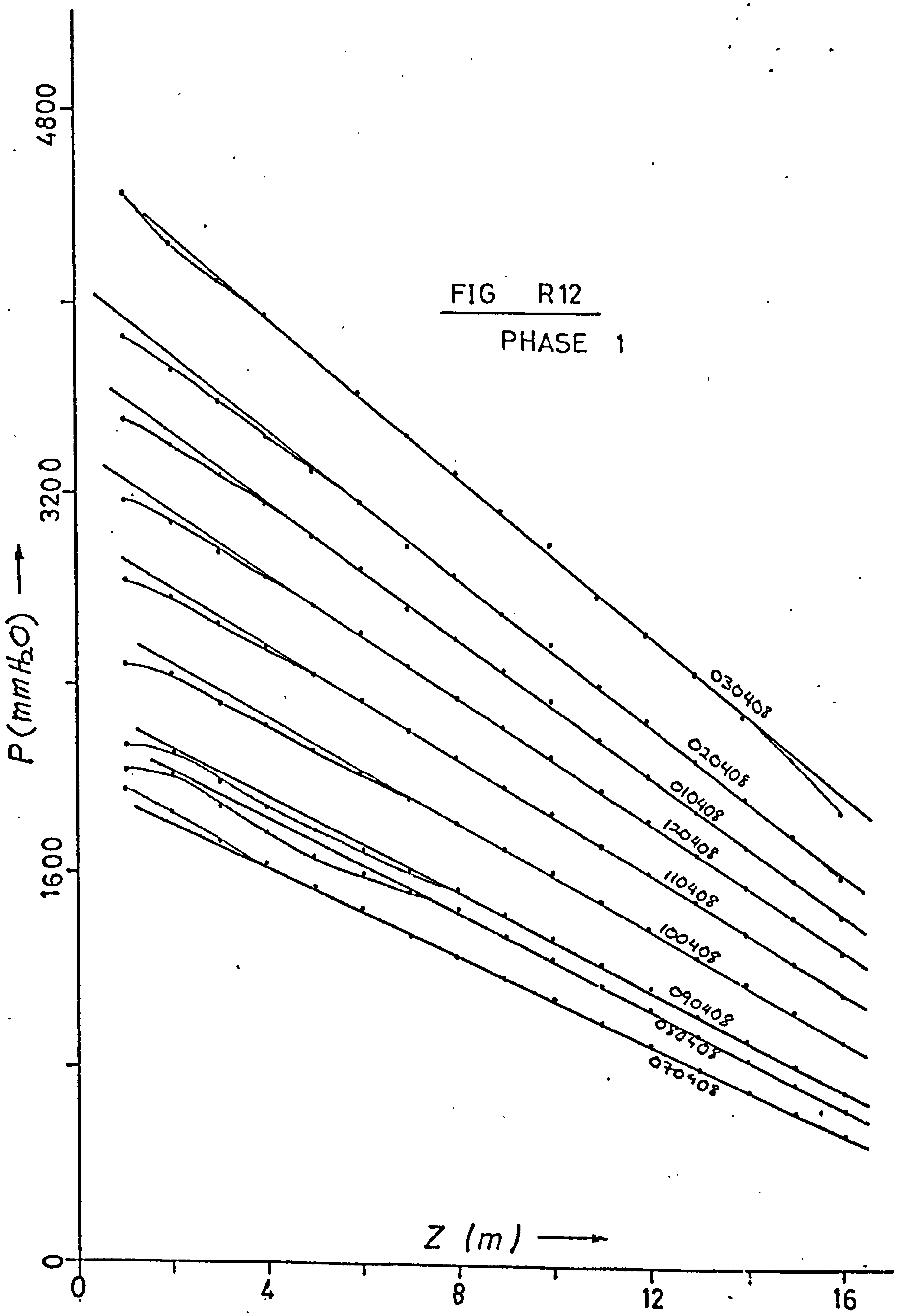


FIG R12

PHASE 1

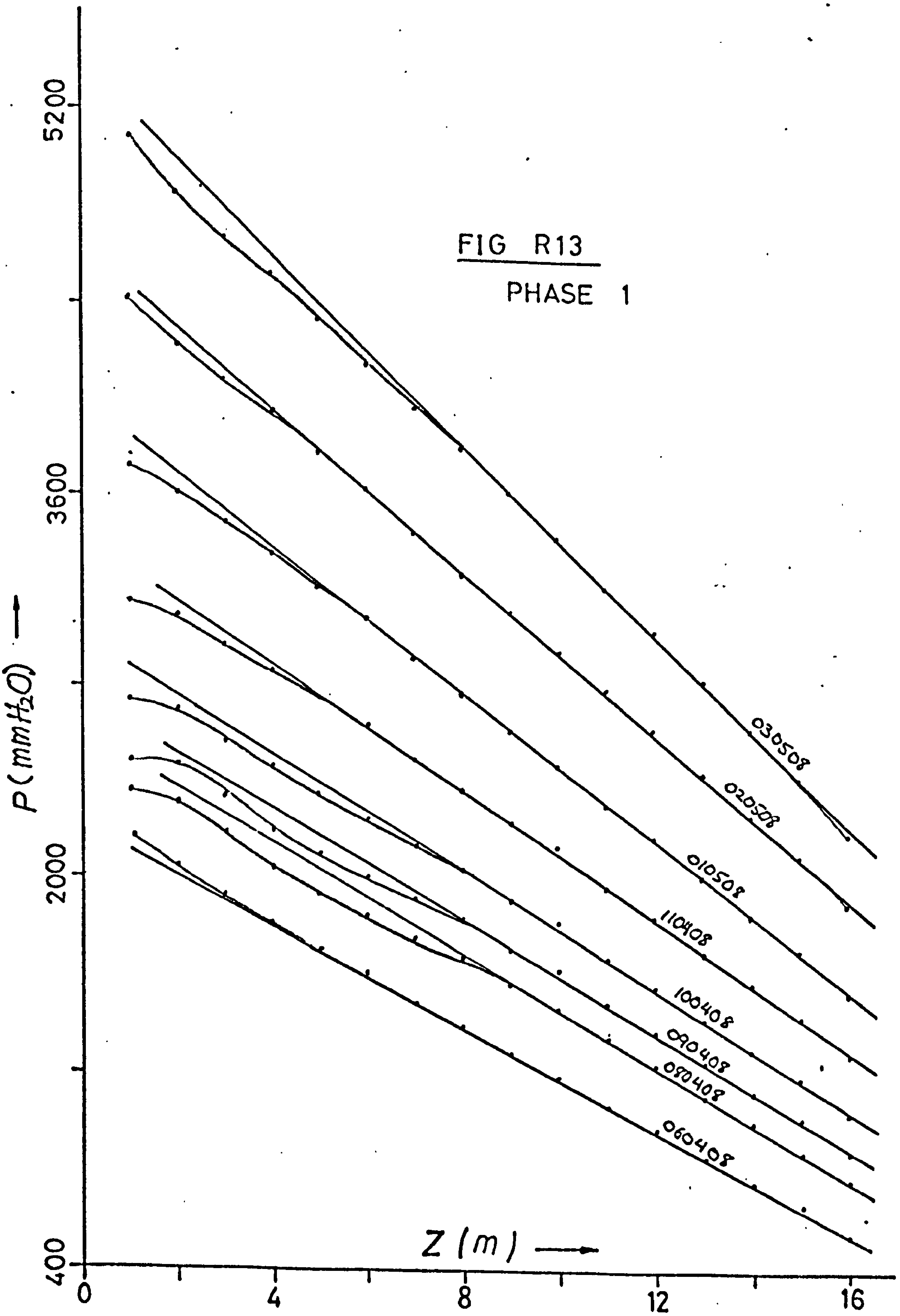


FIG R13

PHASE 1

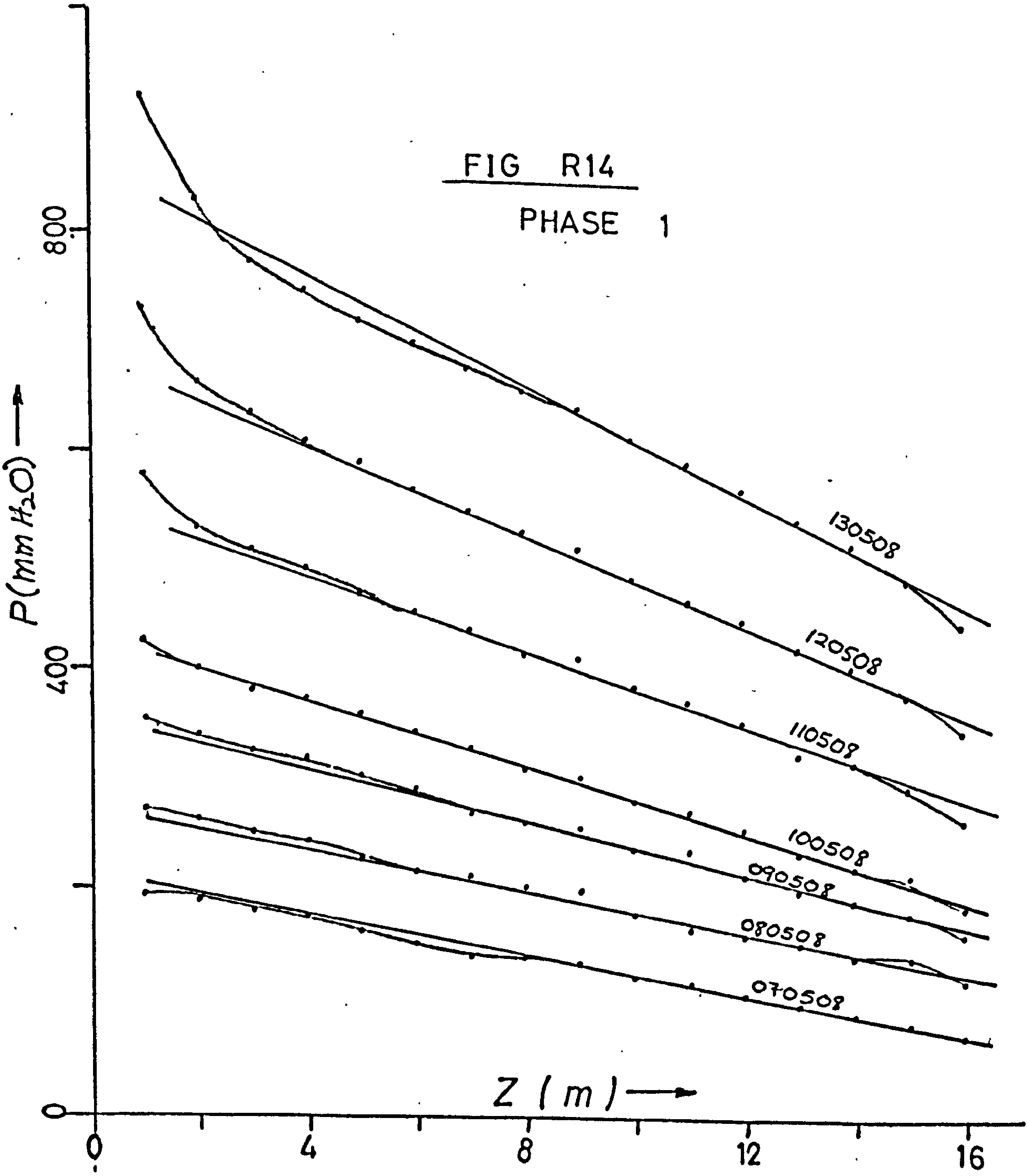
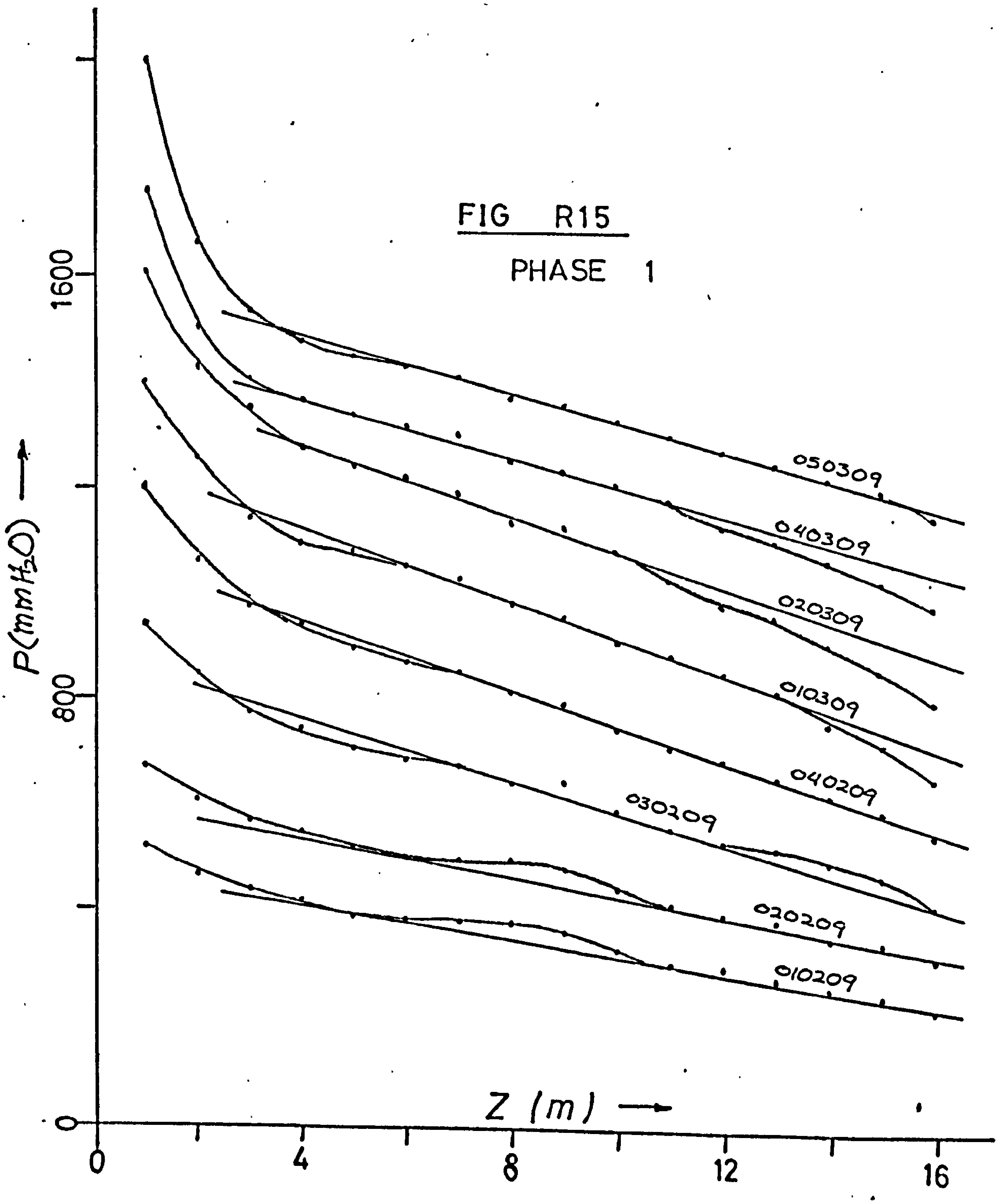


FIG R14

PHASE 1

FIG R15

PHASE 1



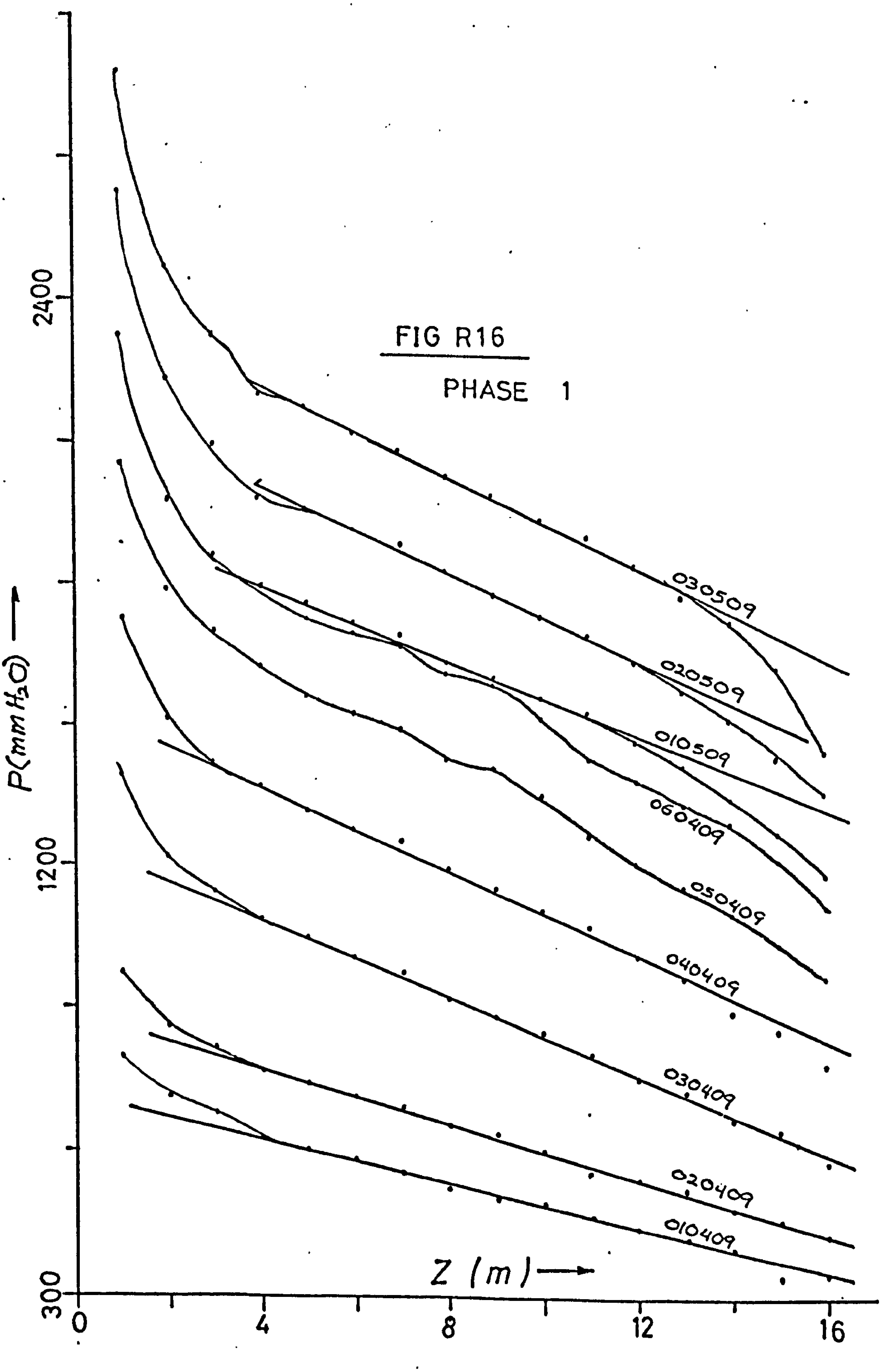


FIG R16

PHASE 1

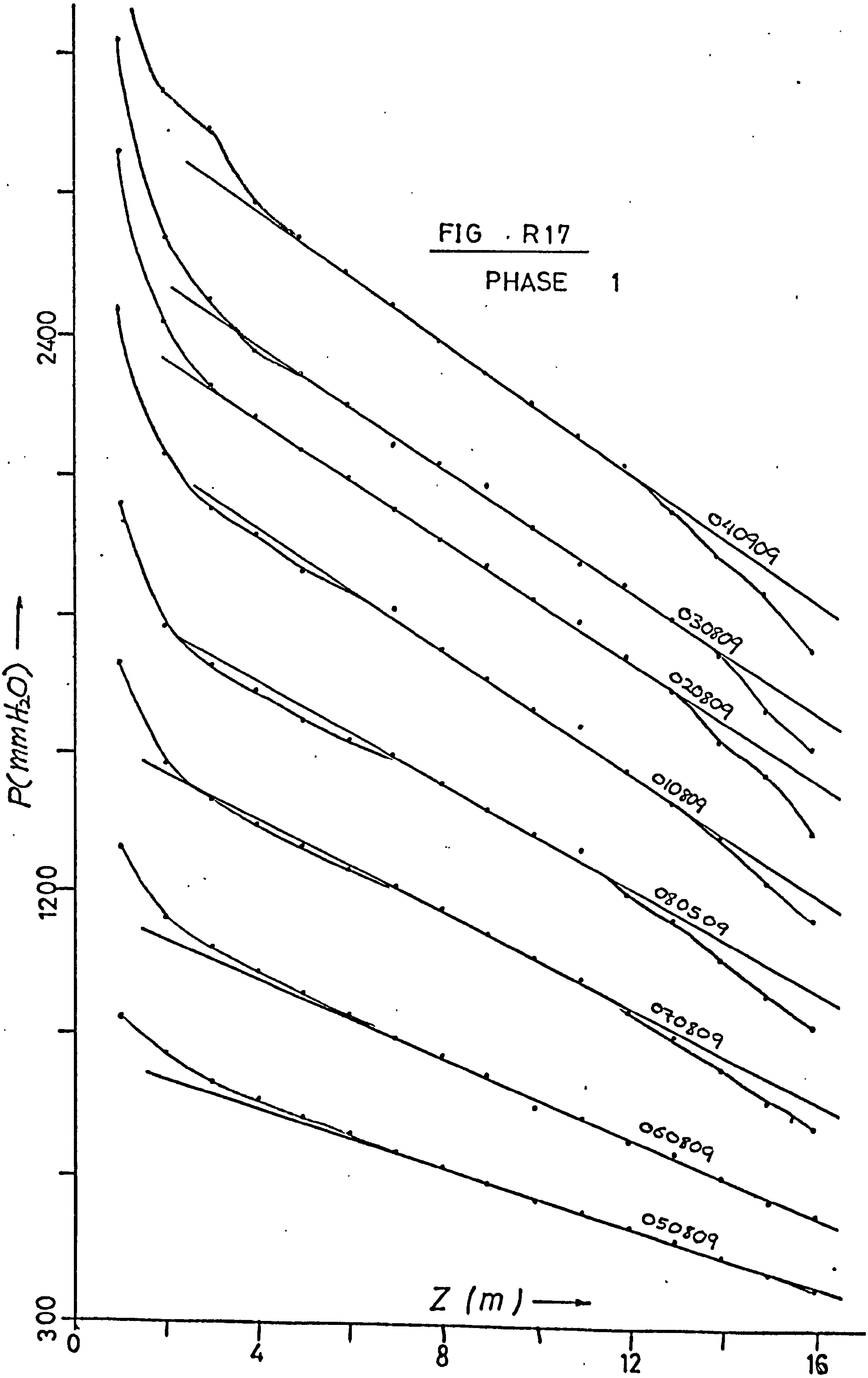


FIG . R17

PHASE 1

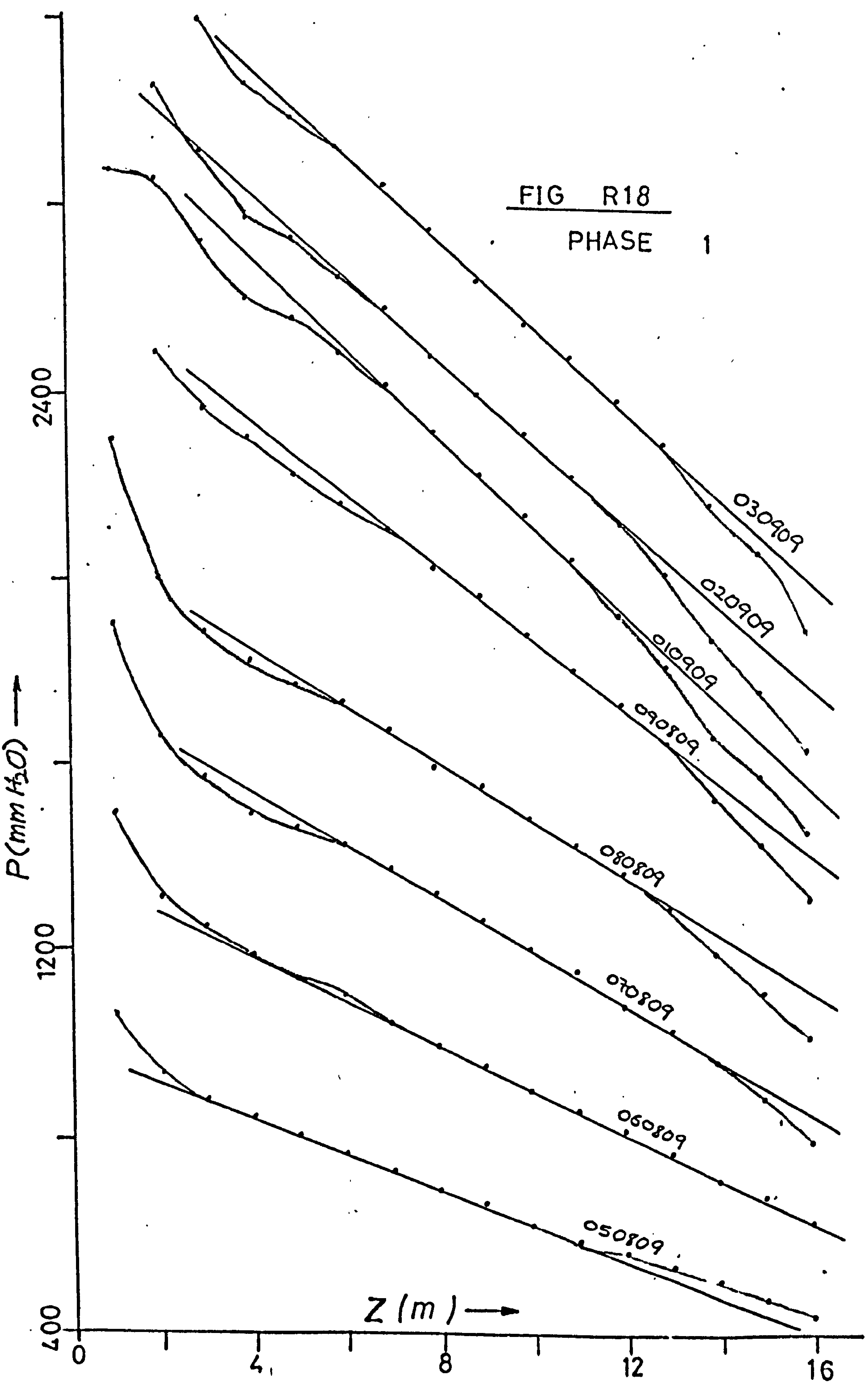
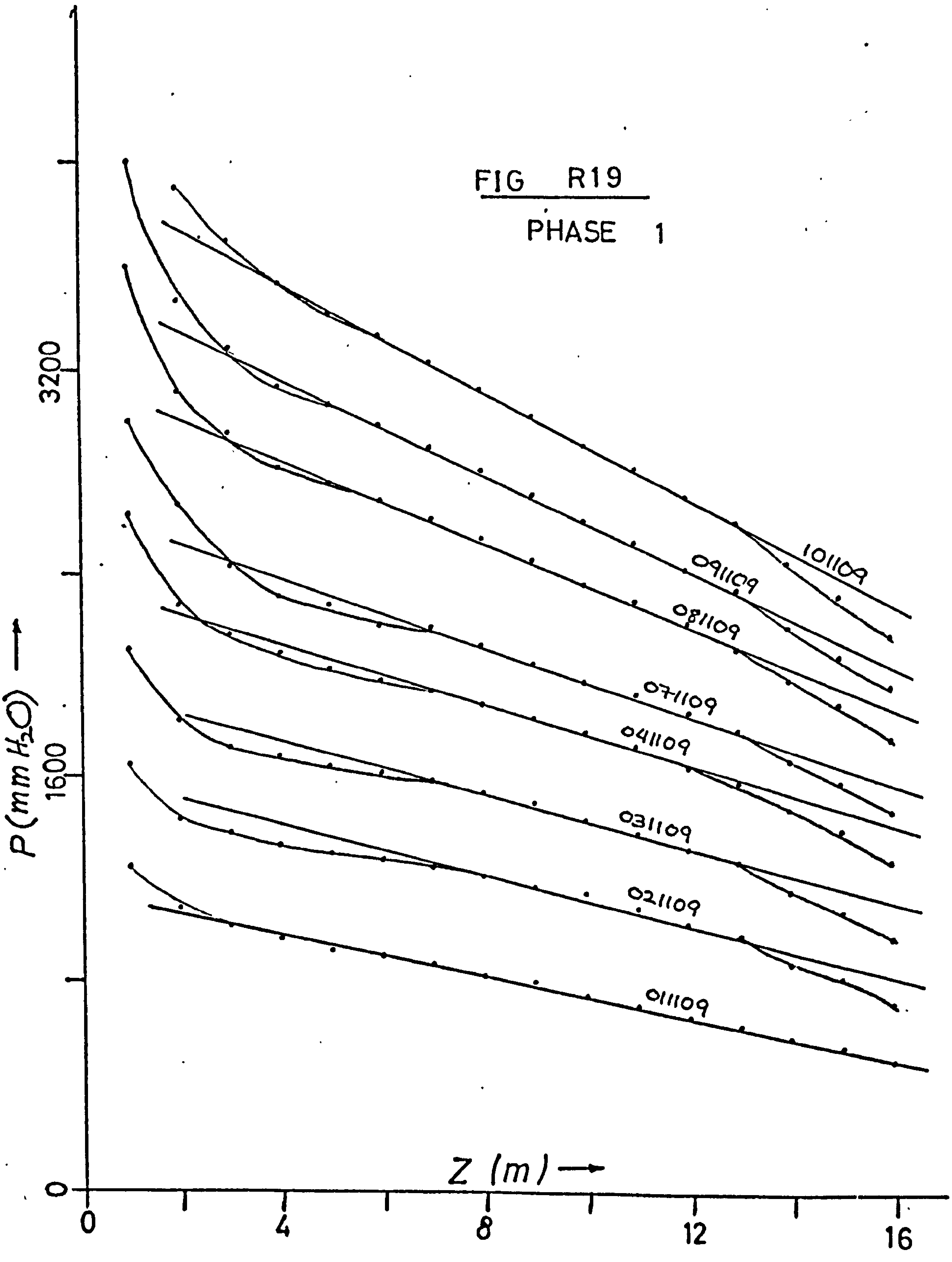


FIG R18

PHASE 1

FIG R19

PHASE 1



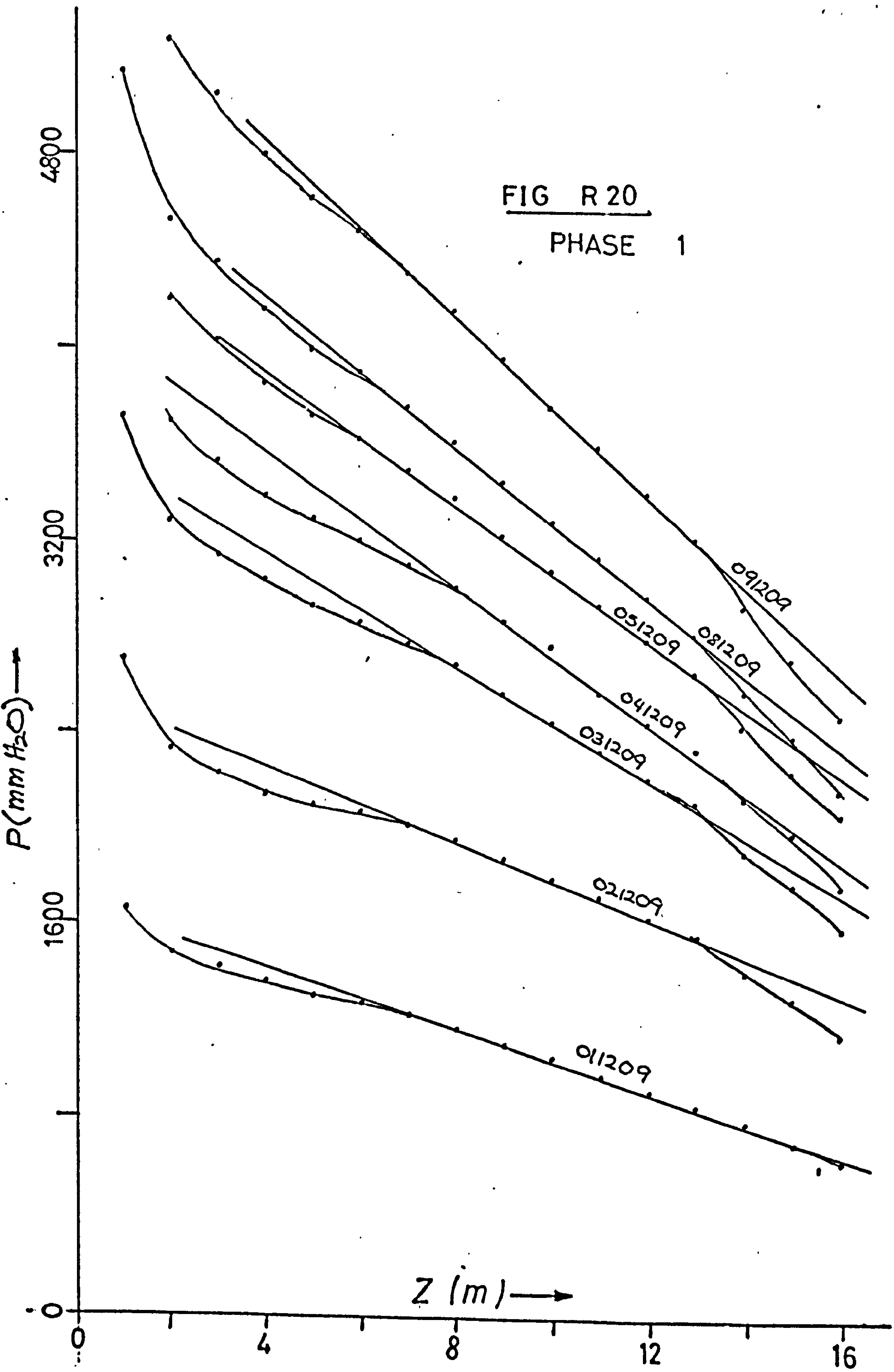


FIG R 20
PHASE 1
P (mm H_2O) ⟶
Z (m) ⟶
0
1600
3200
4800
0
4
8
12
16
091209
081209
051209
041209
031209
021209
011209

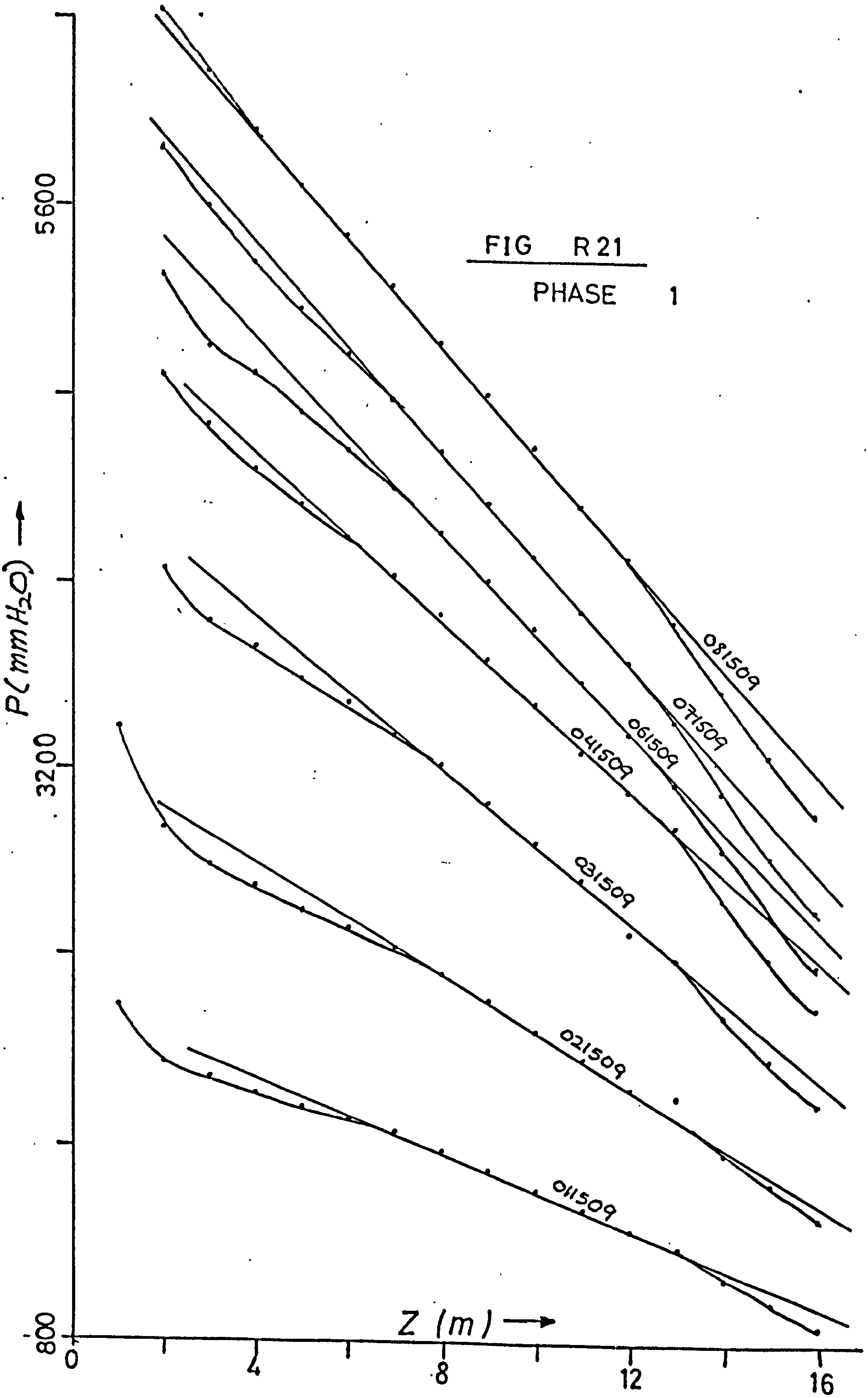


FIG R21

PHASE 1

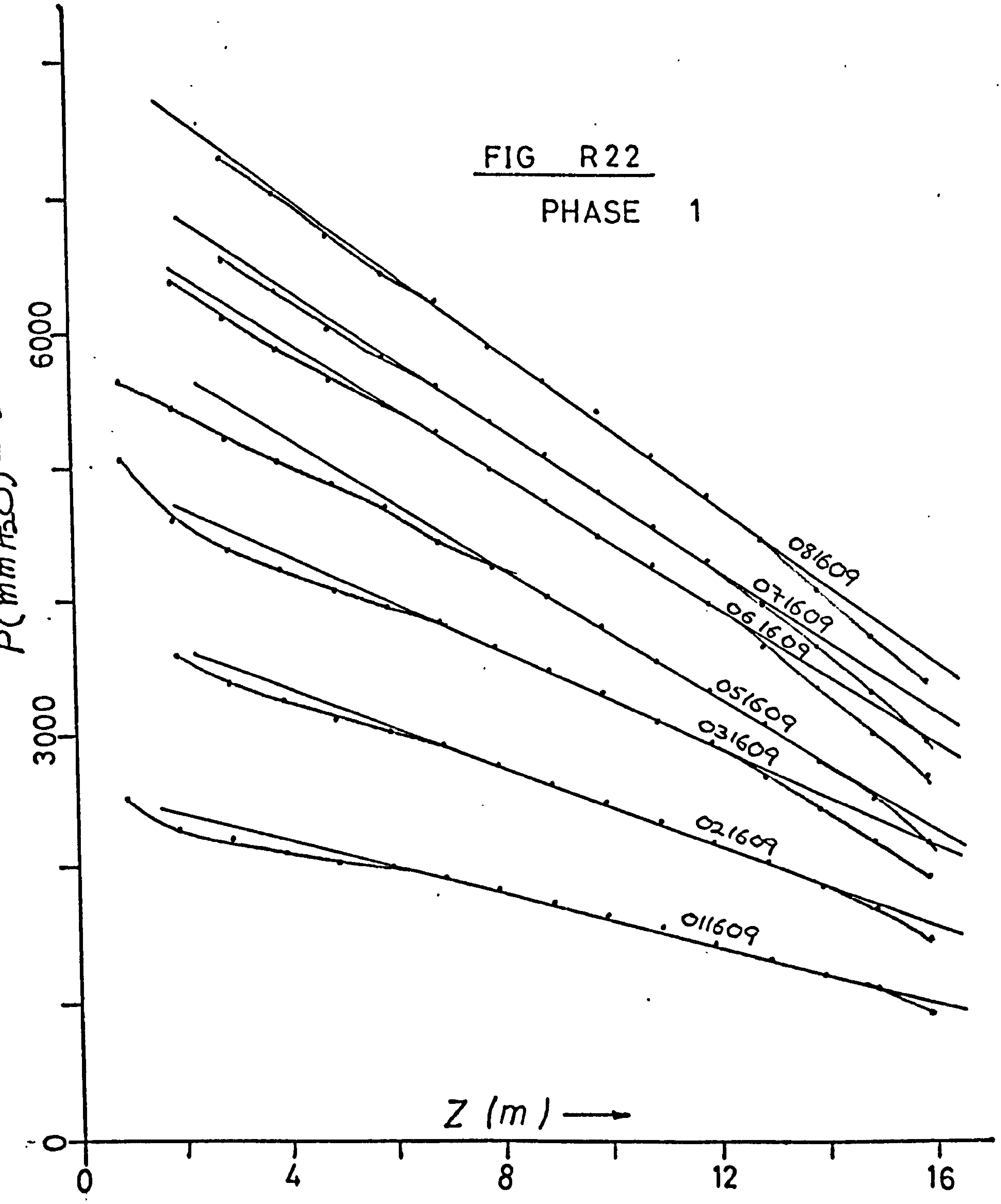


FIG R22
PHASE 1
P(mm H2O) →
Z (m) →
0
3000
6000
0
4
8
12
16
081609
071609
061609
051609
031609
021609
011609

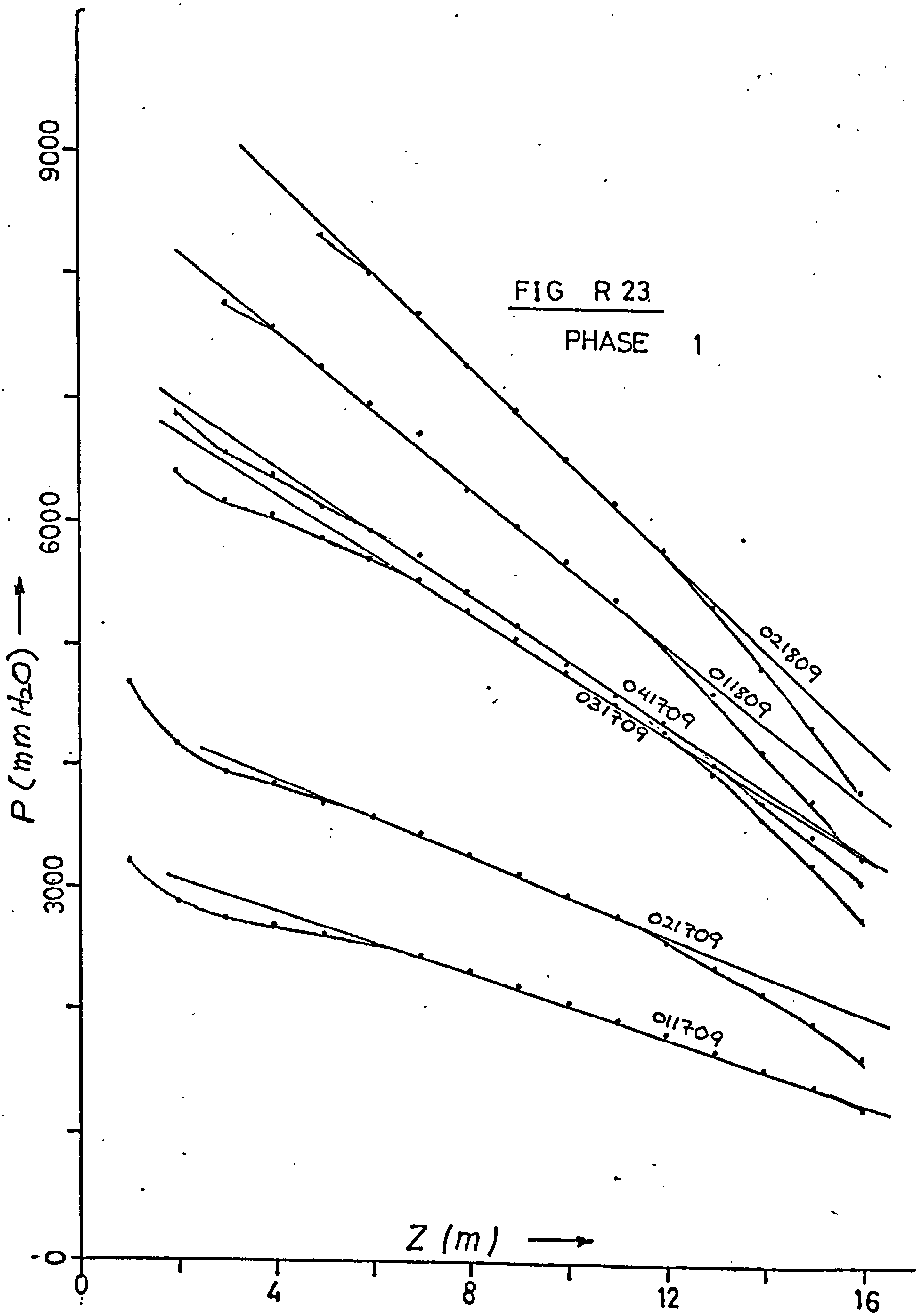


FIG R 23

PHASE 1

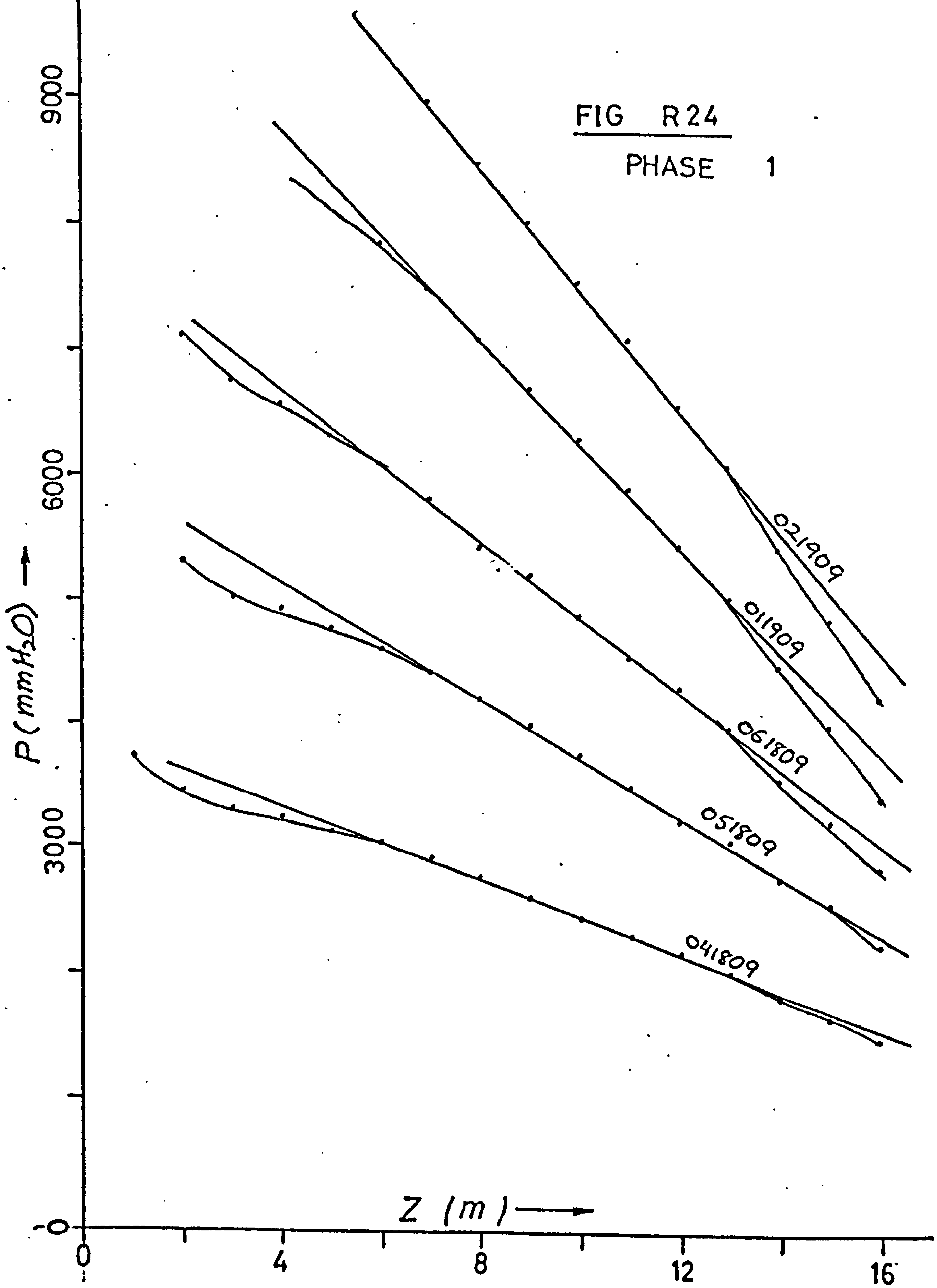


FIG R24

PHASE 1

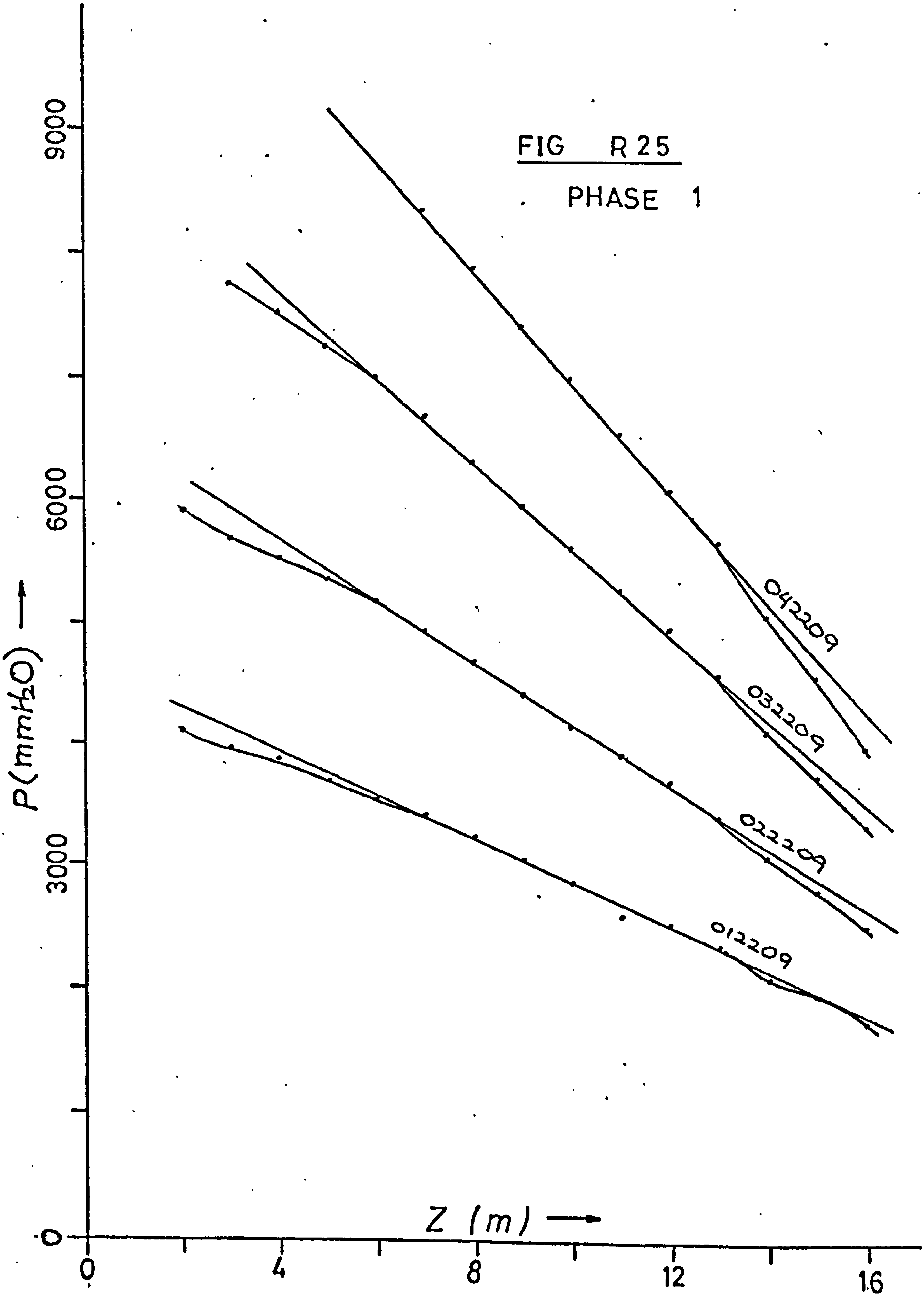


FIG R 25
PHASE 1
P(mmH₂O) →
9000
6000
3000
0
Z (m) →
0
4
8
12
16
042209
032209
022209
012209

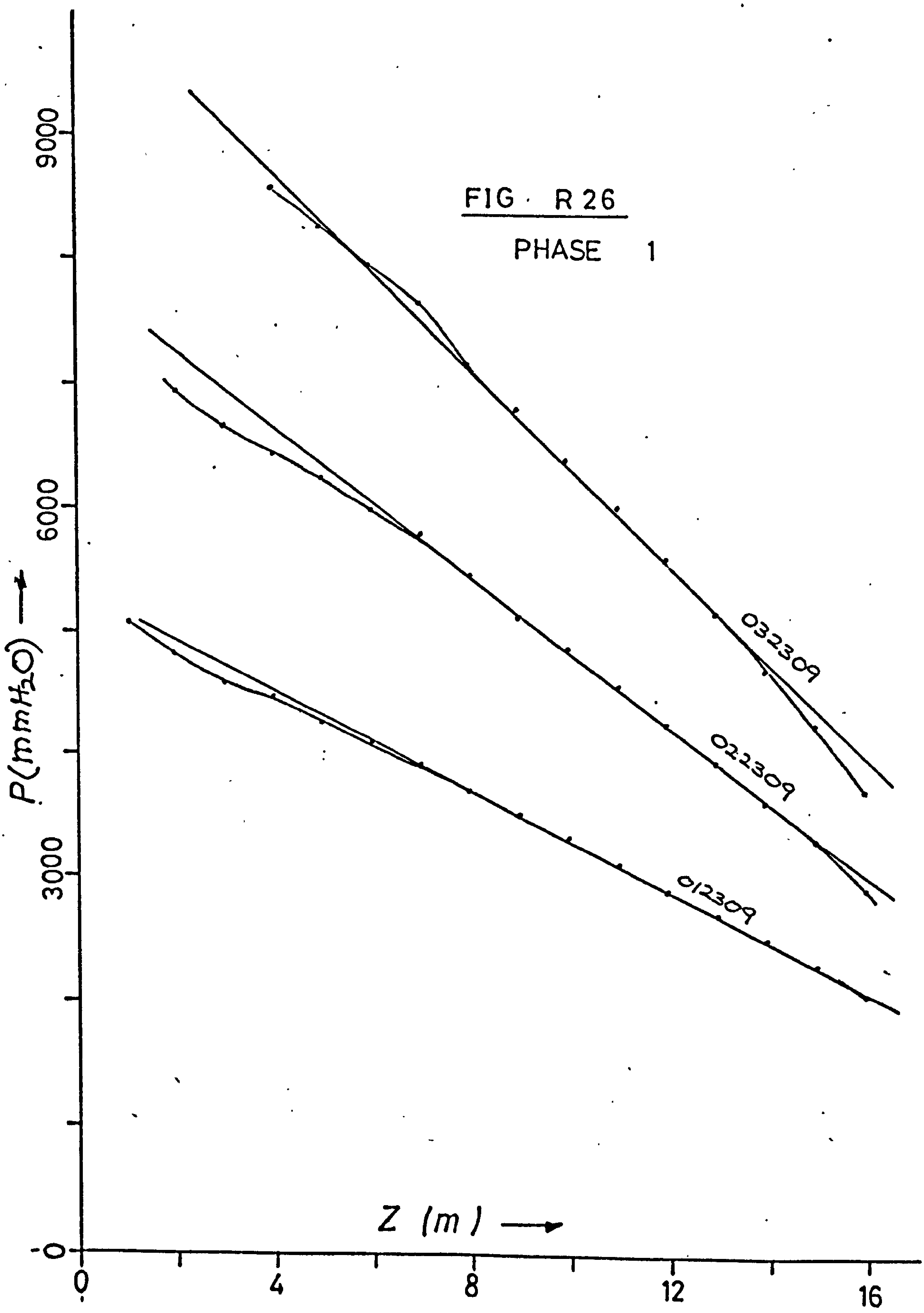


FIG · R 26
PHASE 1
9000
6000
3000
-0
P(mmH₂O) →
Z (m) →
0
4
8
12
16
032309
022309
012309

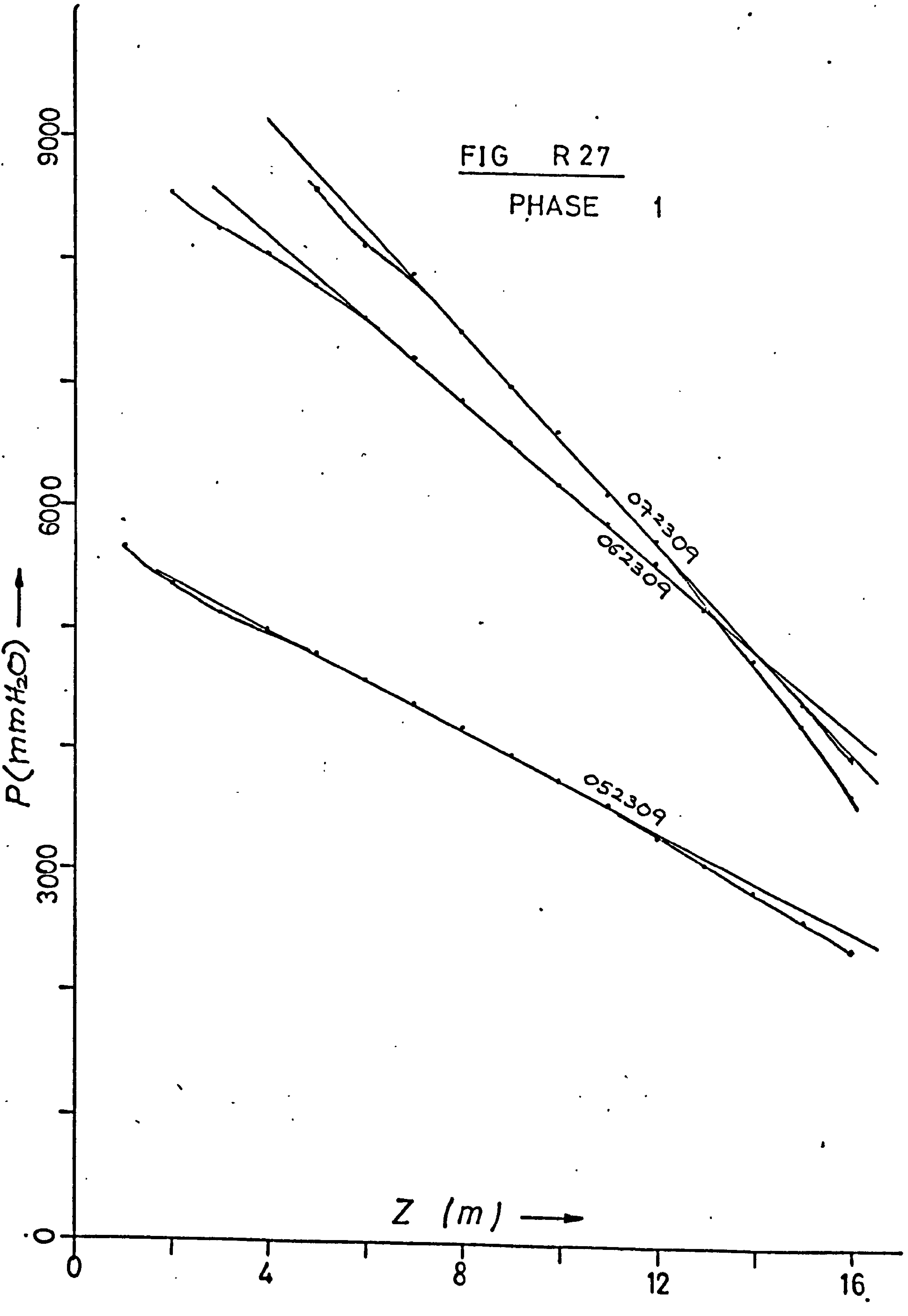


FIG R 27

PHASE 1

FIG R28

PHASE 2

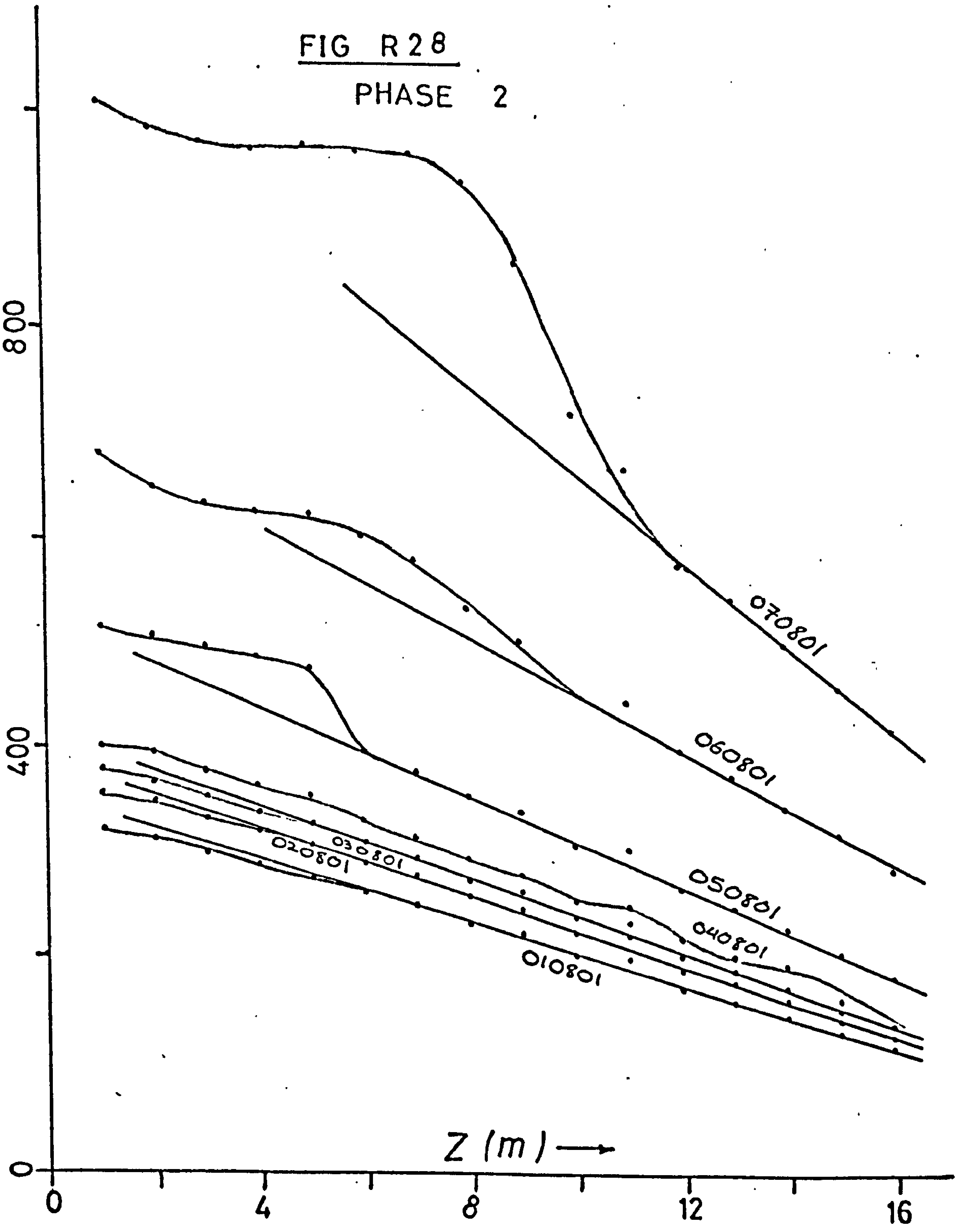


FIG R 29

PHASE 2

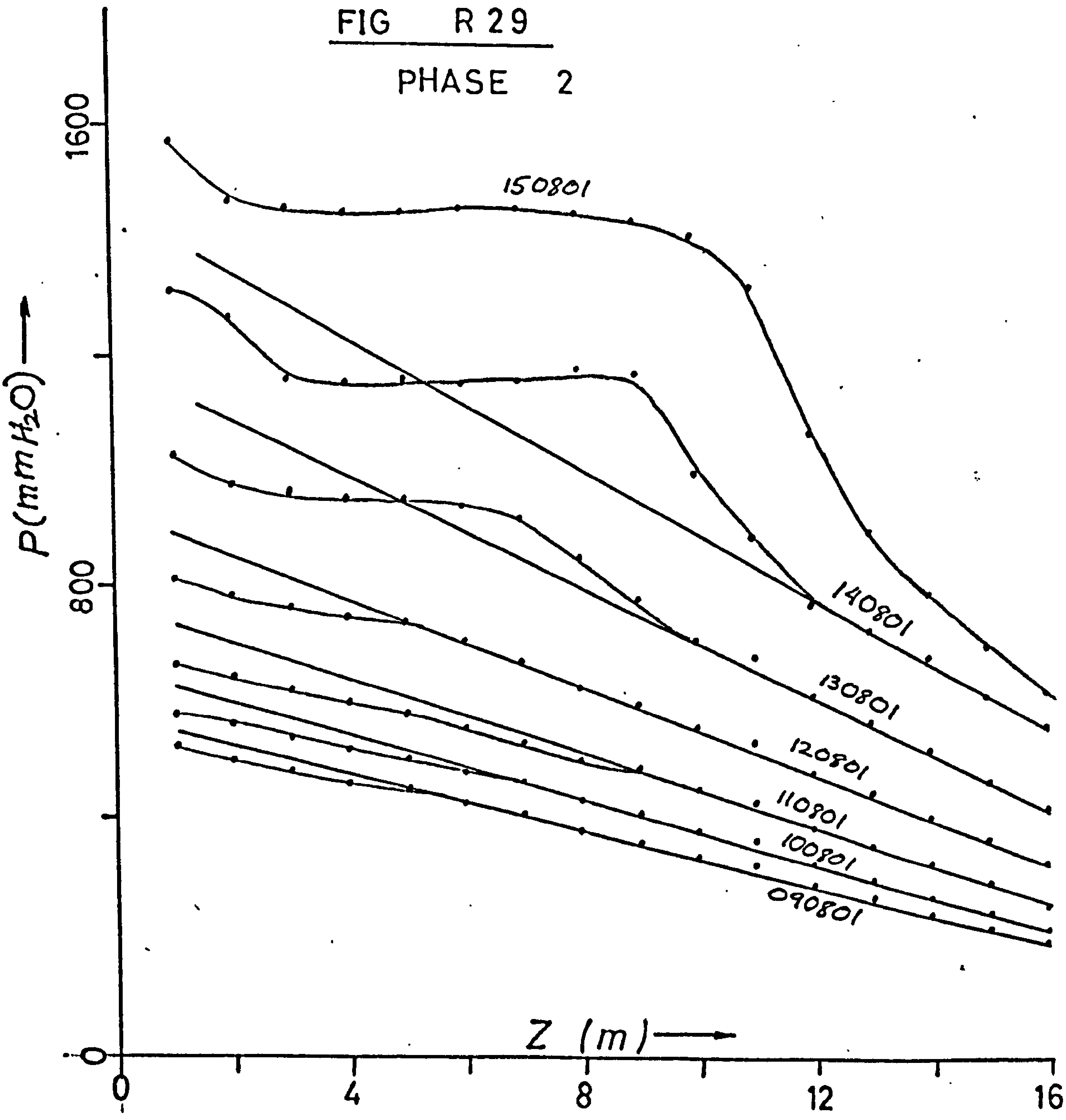


FIG R30

PHASE 2

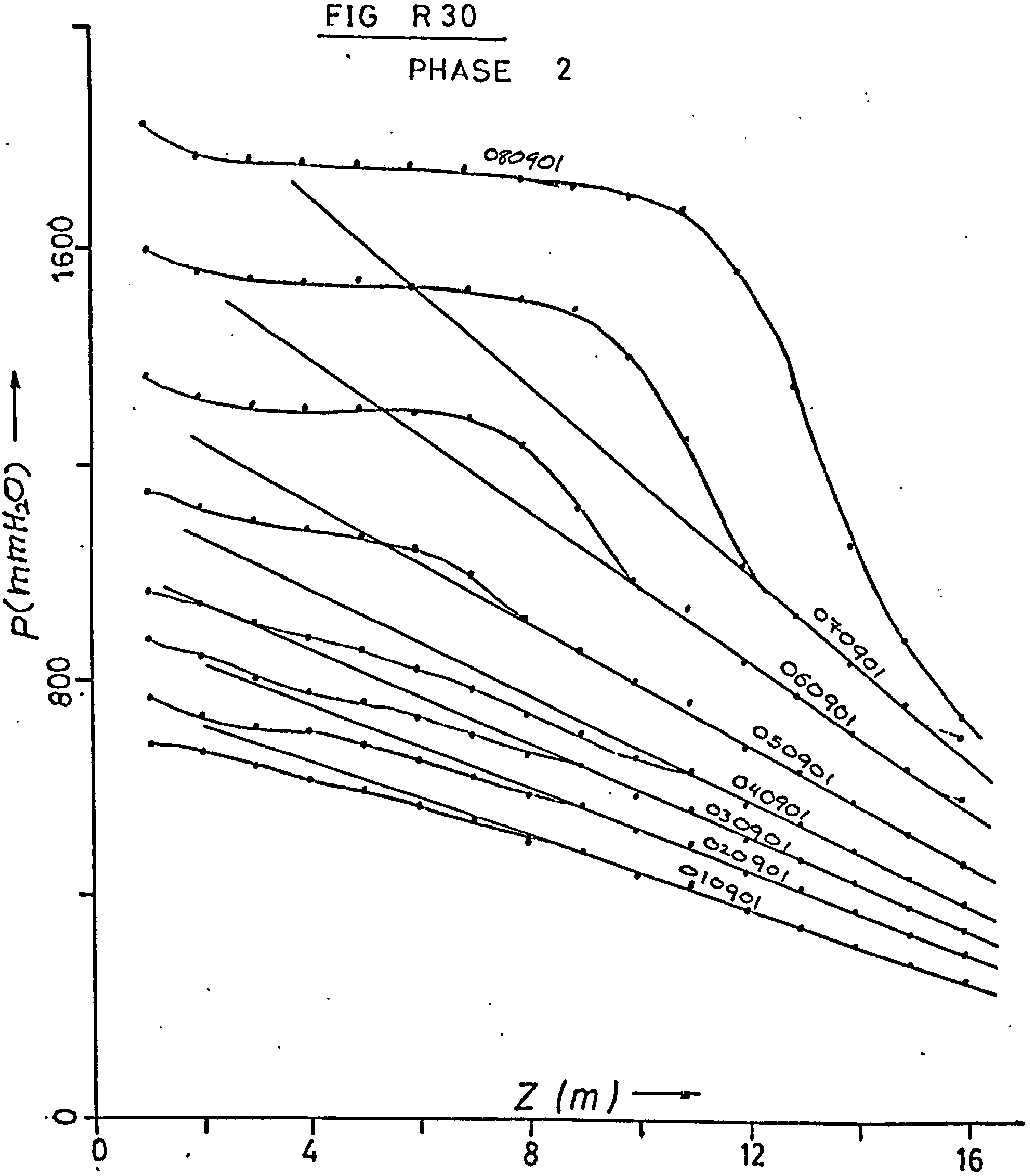


FIG R31

PHASE 2

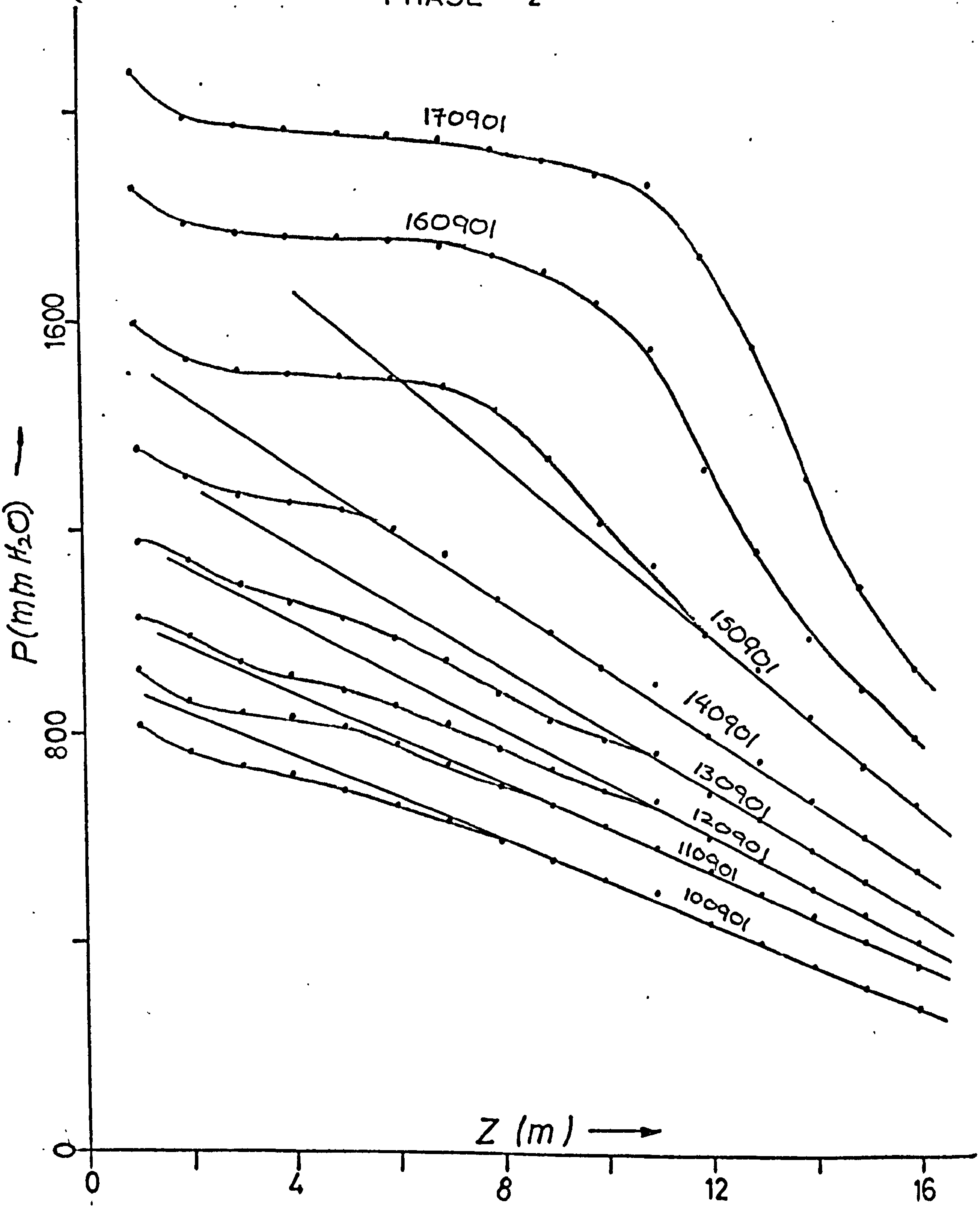
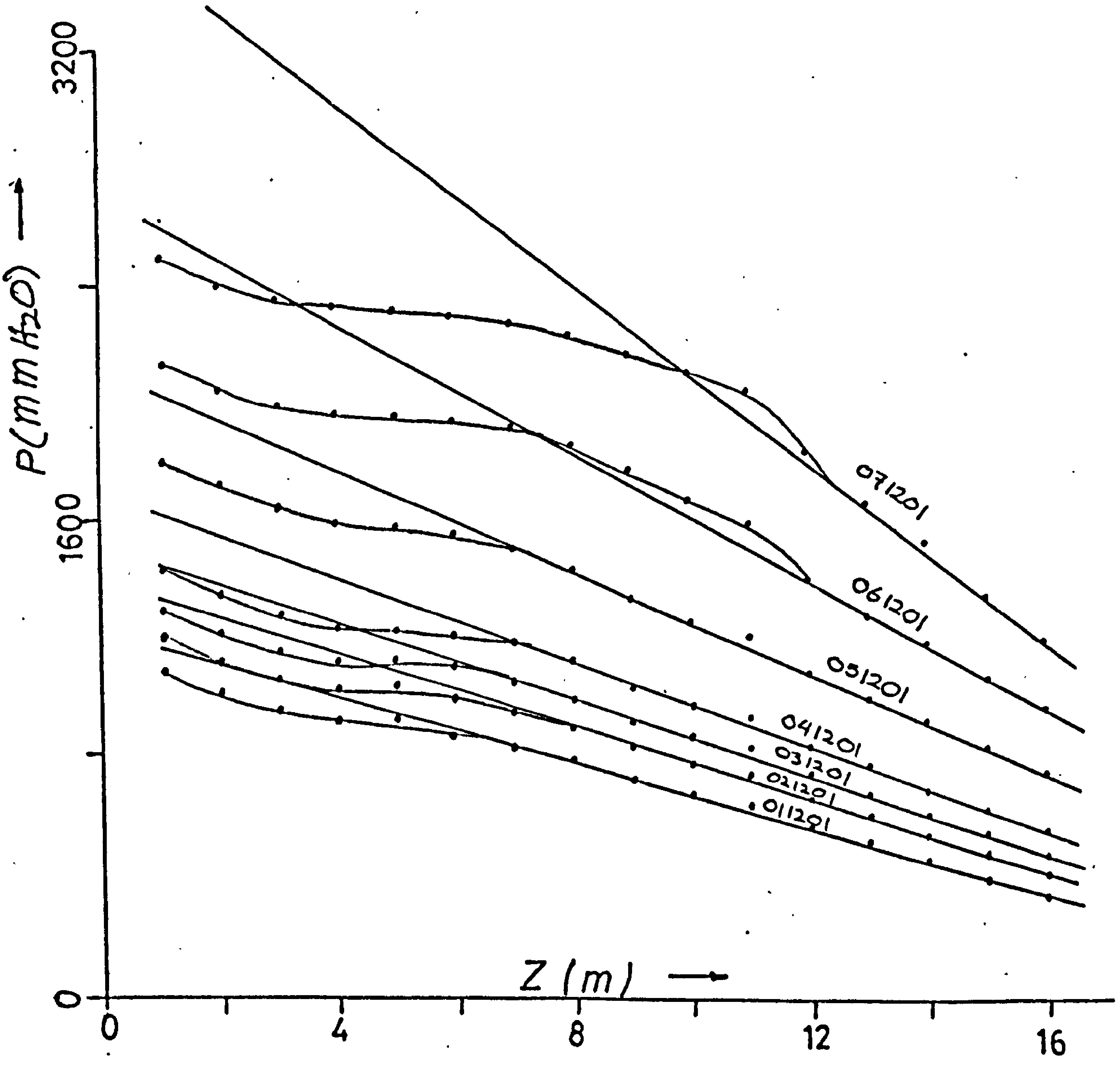


FIG R32

PHASE 2



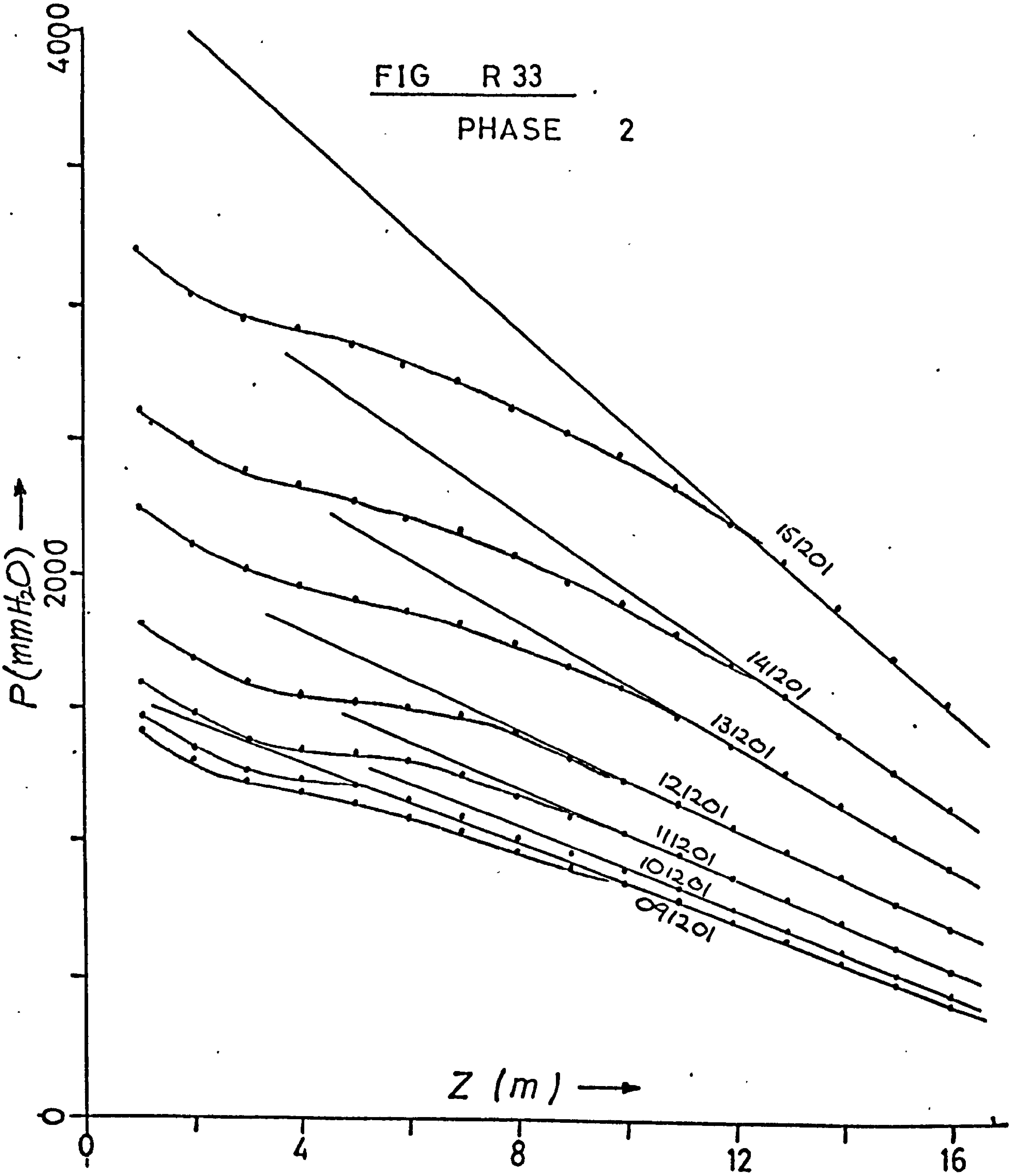


FIG R 33

PHASE 2

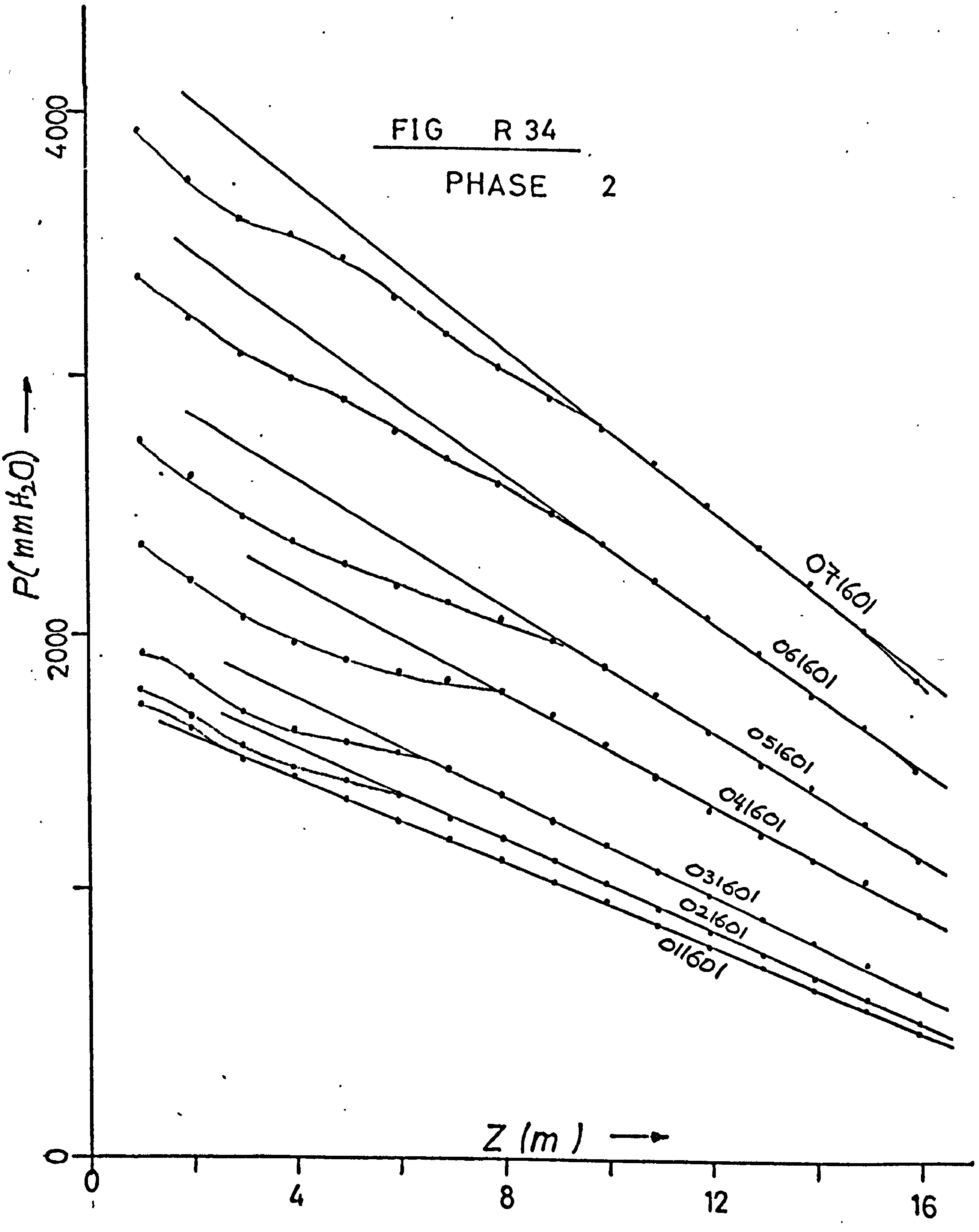


FIG R 34
PHASE 2
P(mm H₂O)
4000
2000
0
Z (m)
0
4
8
12
16
071601
061601
051601
041601
031601
021601
011601

FIG R 35

PHASE 2

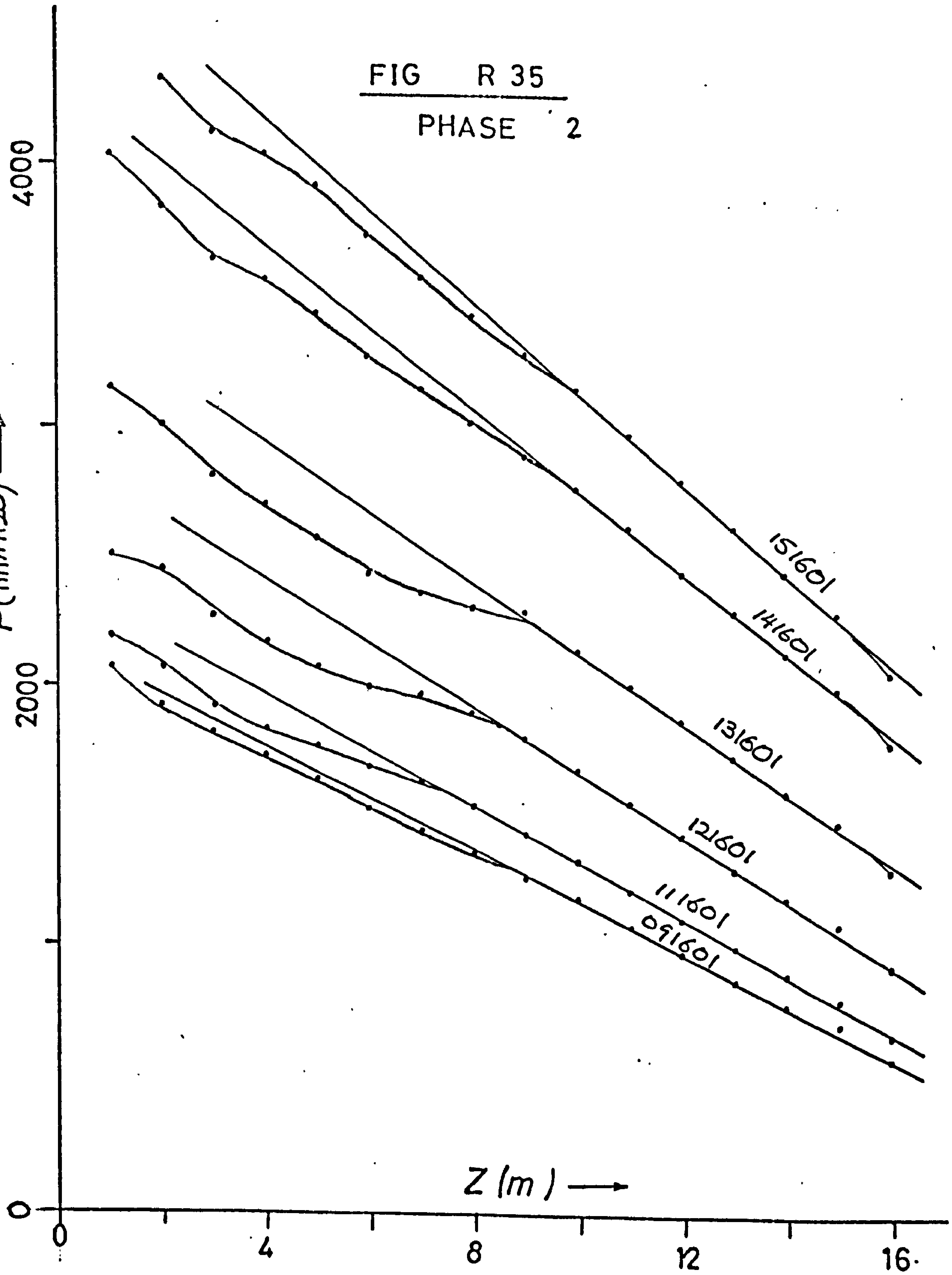
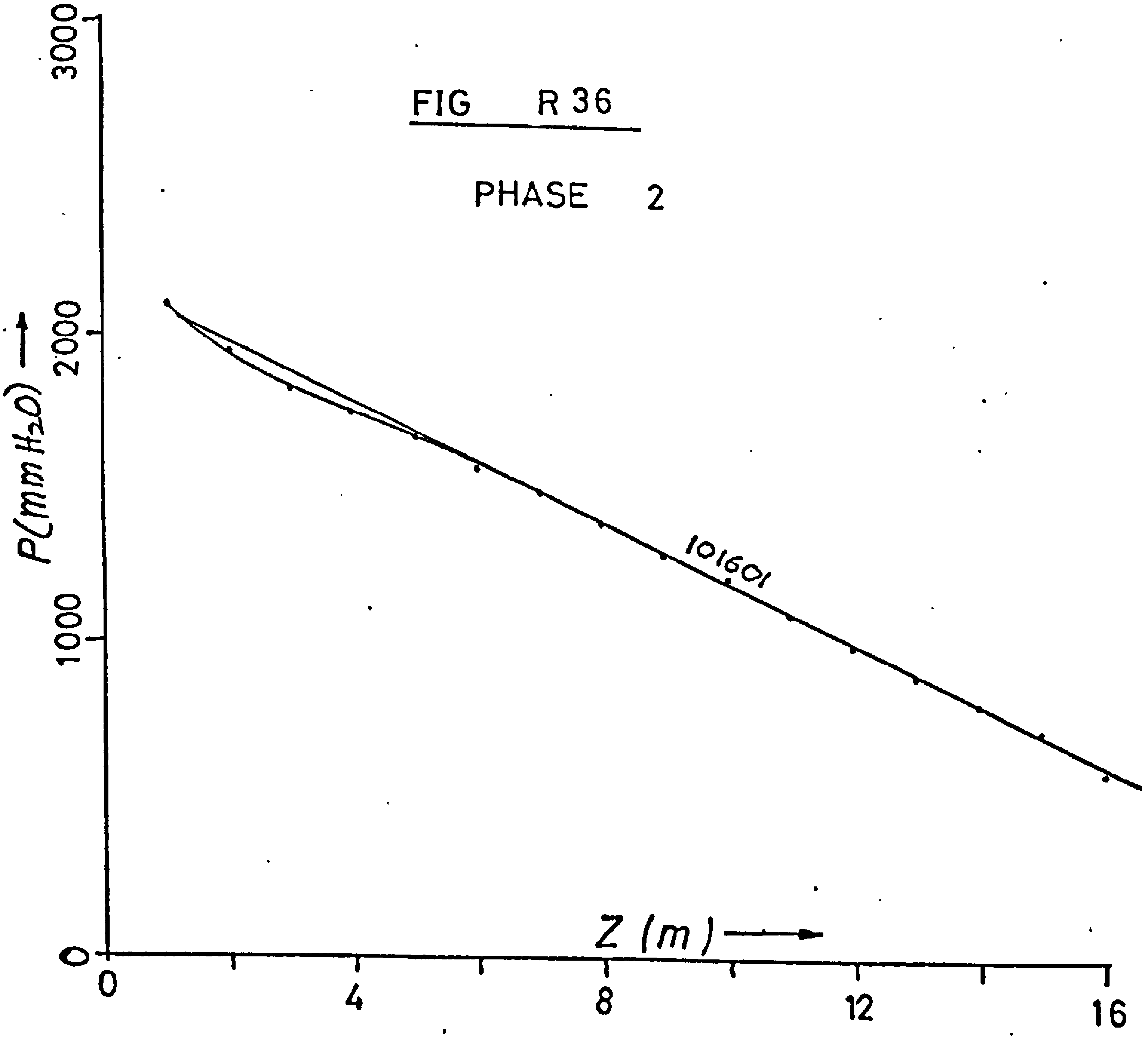


FIG R 36

PHASE 2



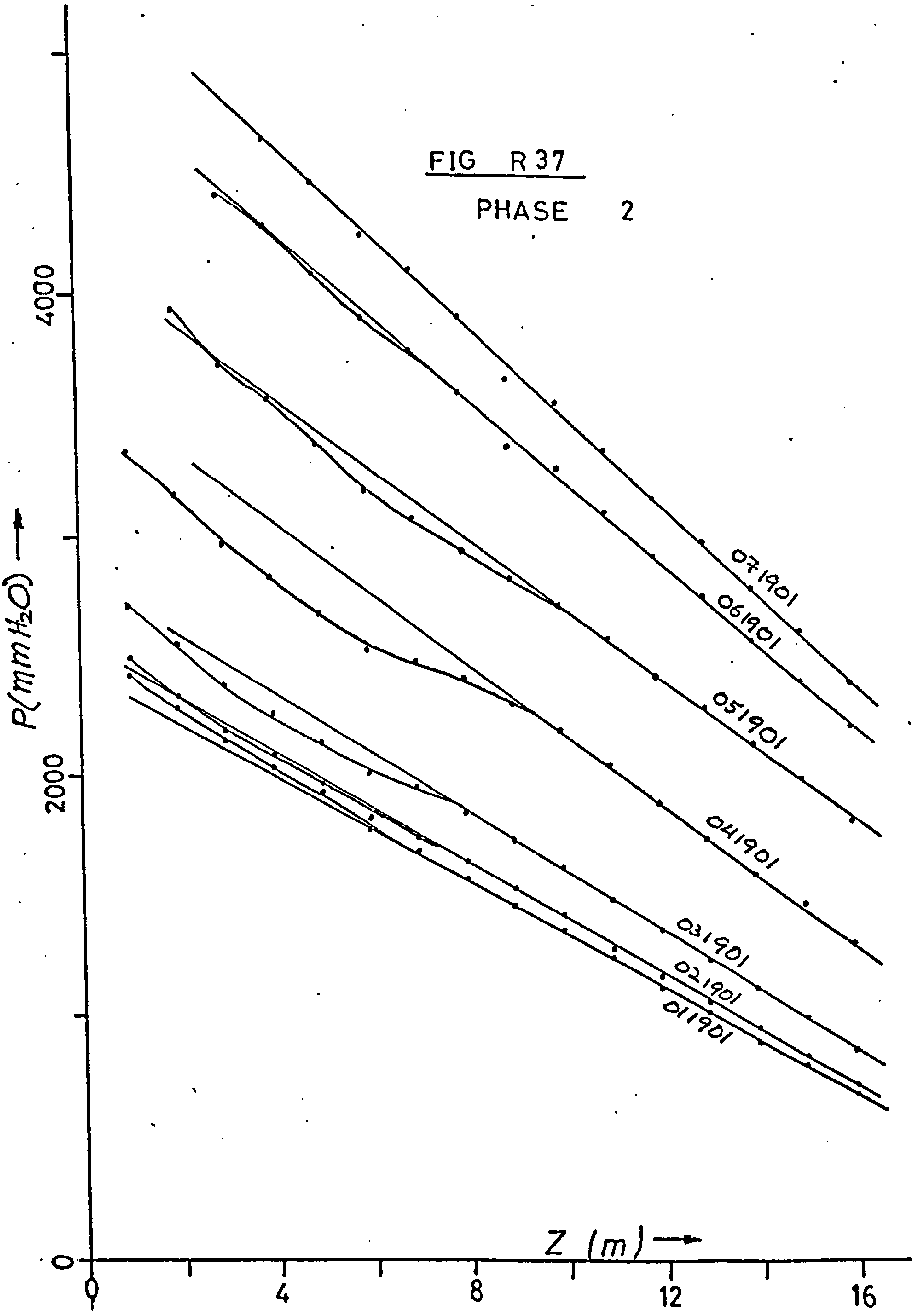


FIG R 37
PHASE 2
P(mm H_2O) →
4000
2000
0
Z (m) →
0
4
8
12
16
071901
061901
051901
041901
031901
021901
011901

FIG R 38

PHASE 2

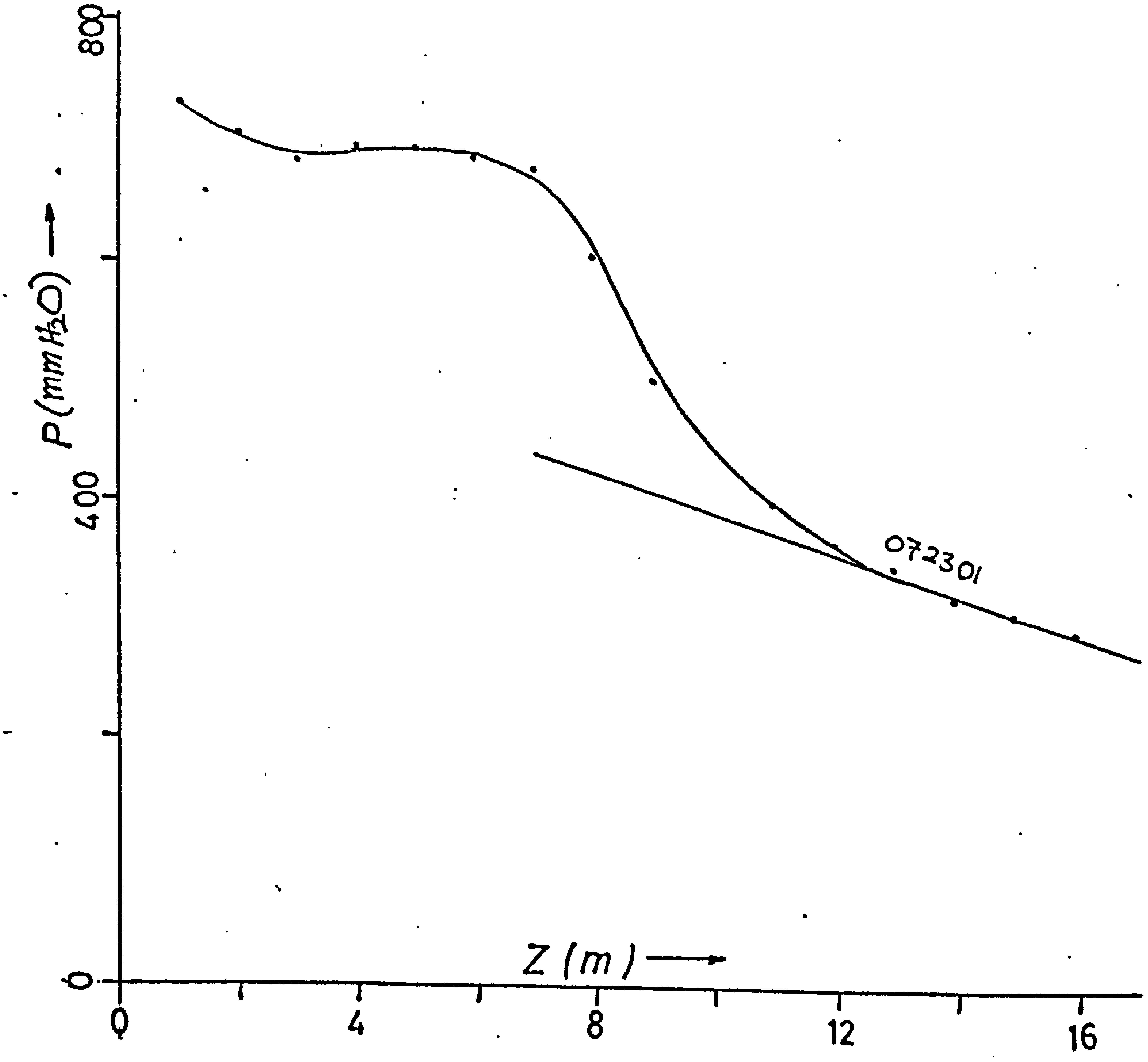


FIG R.39

PHASE 2

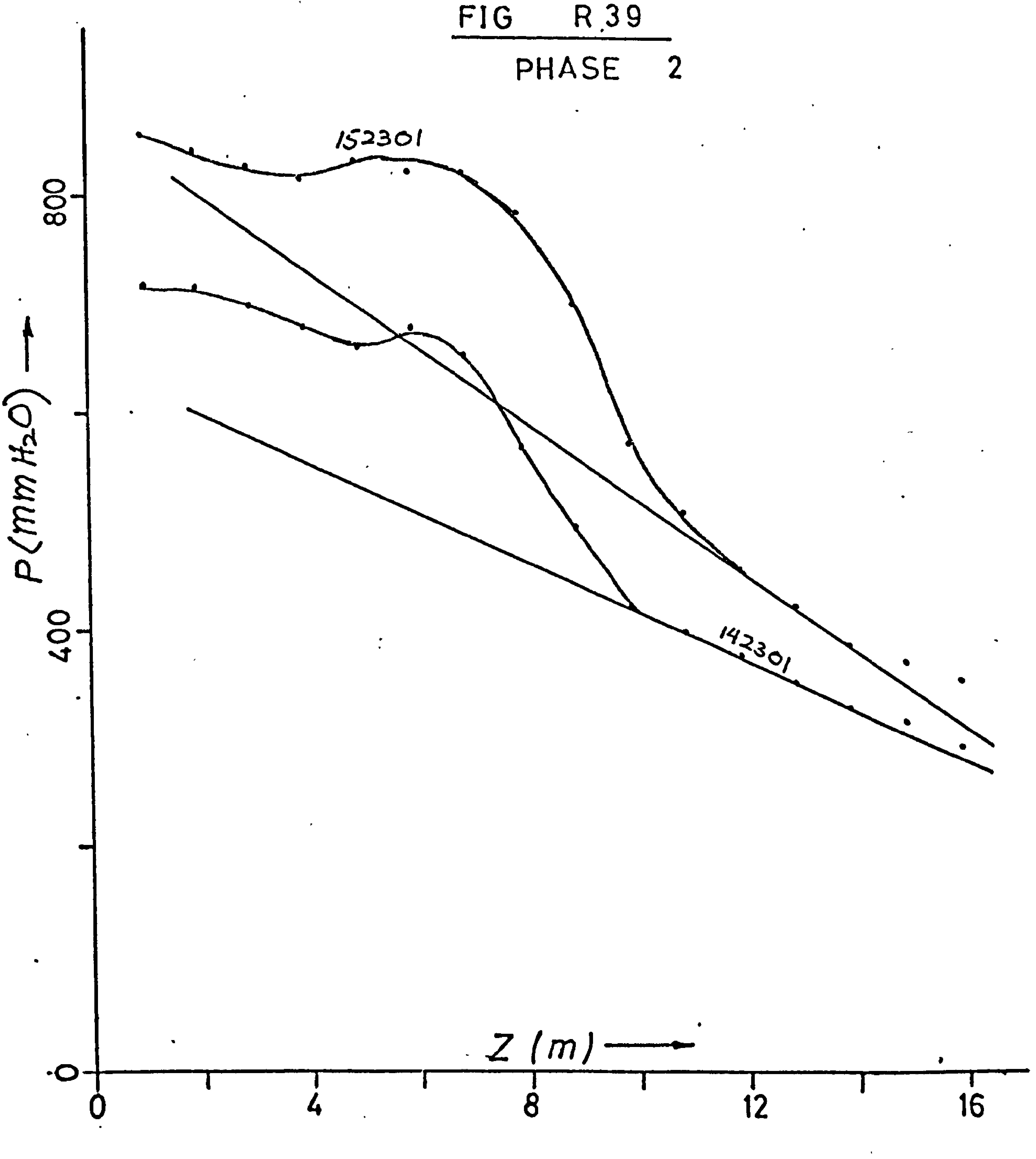
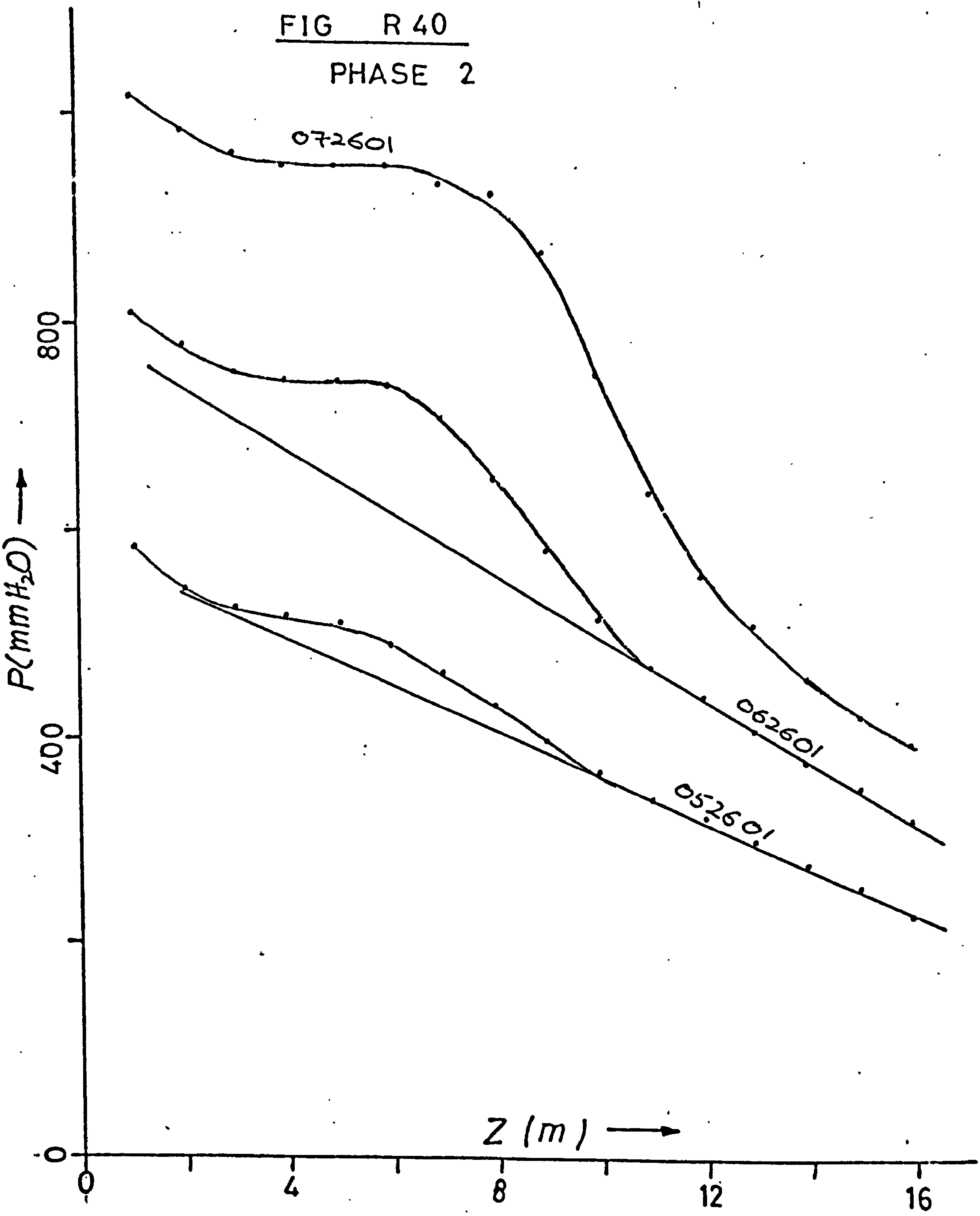


FIG R 40

PHASE 2



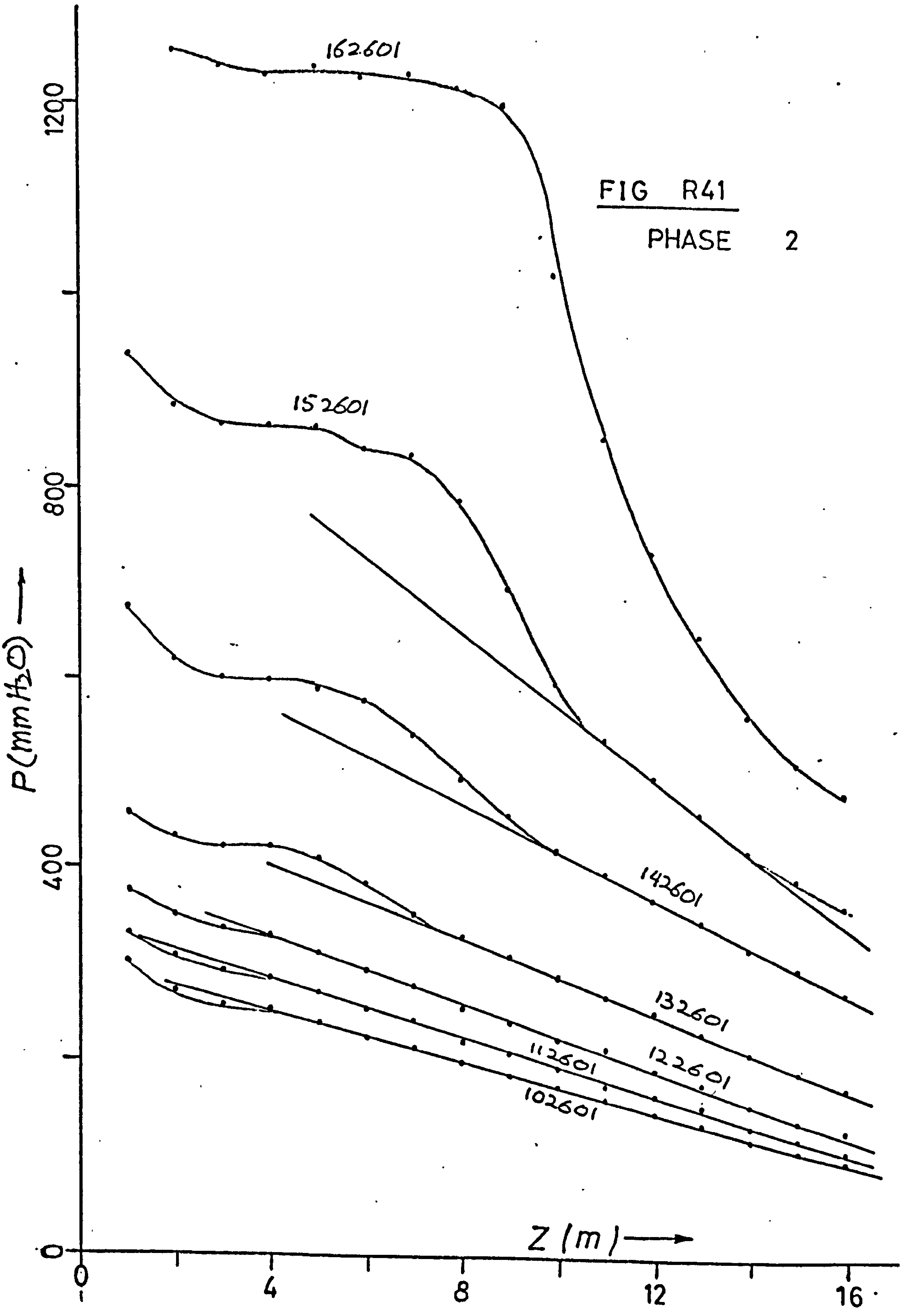


FIG R41

PHASE 2

FIG R 42

PHASE 2

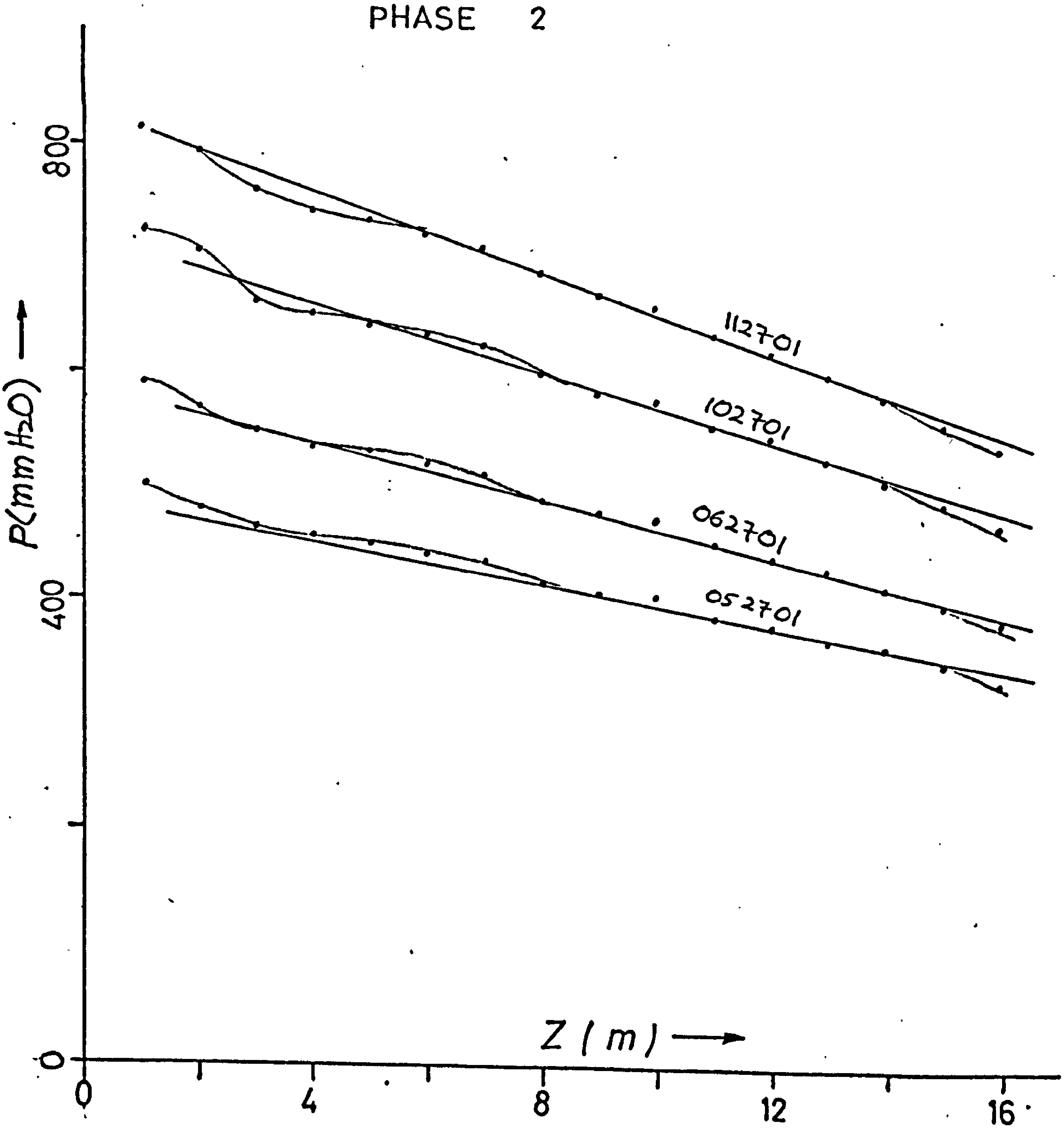
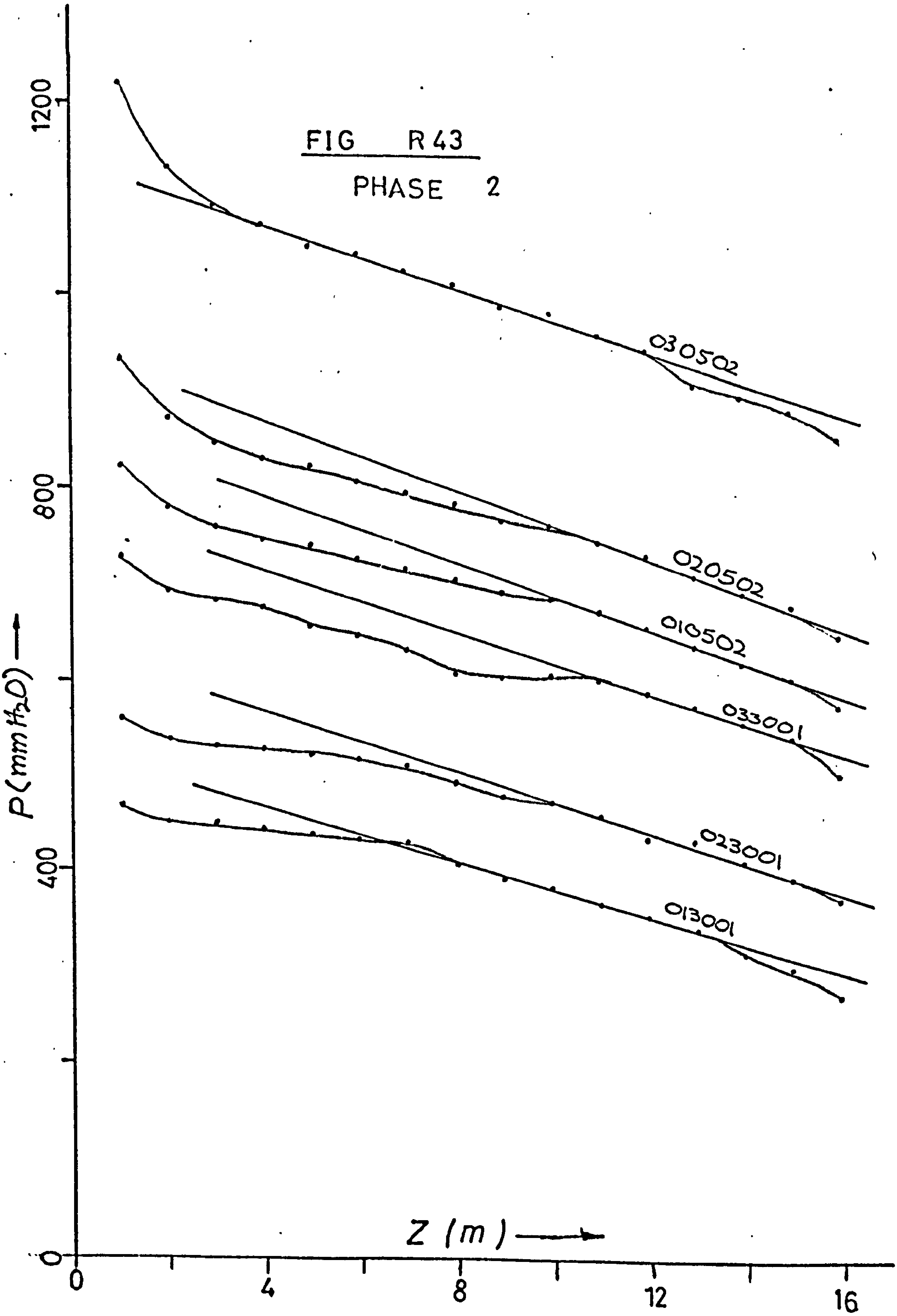


FIG R43

PHASE 2



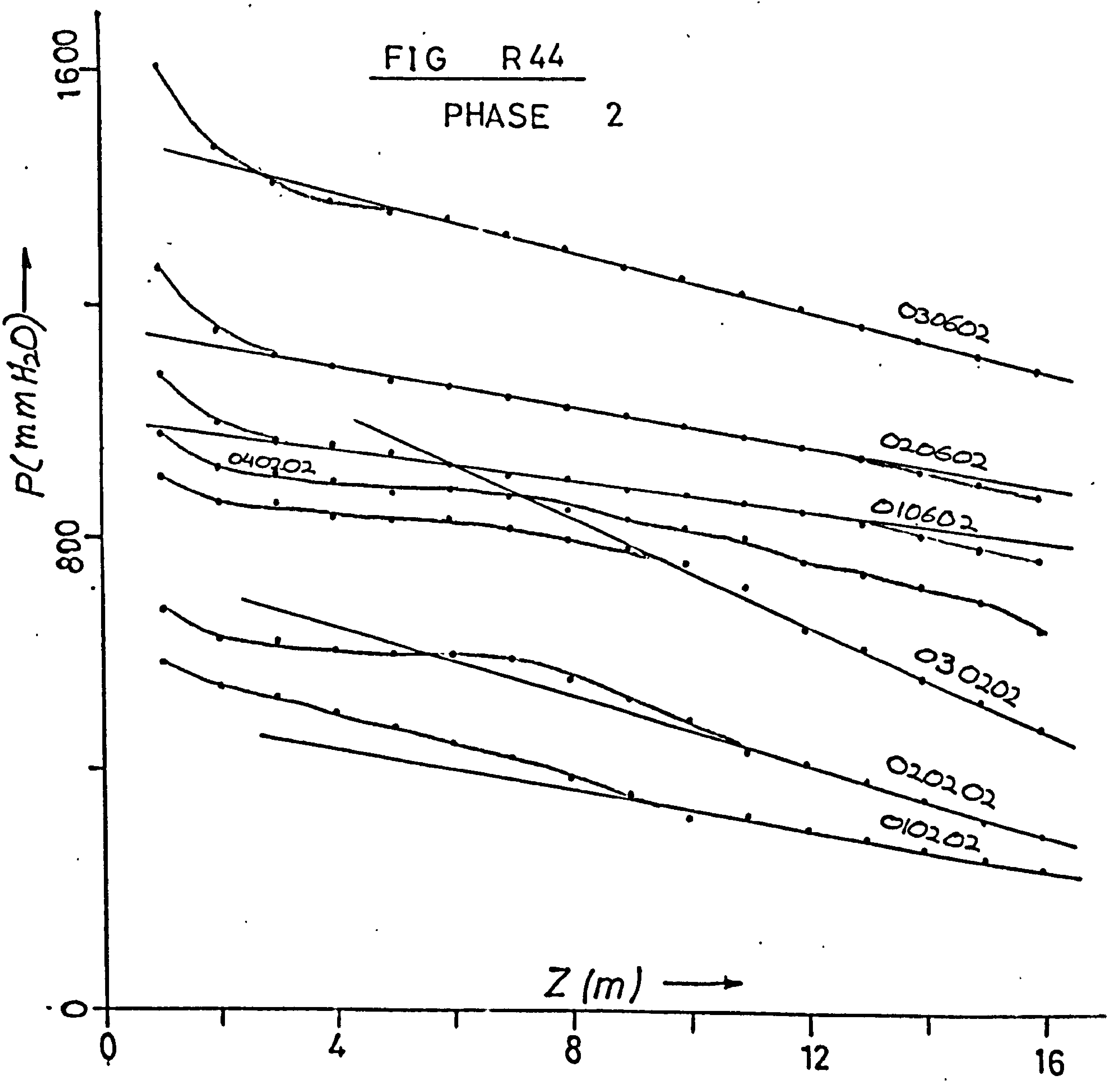


FIG R44
PHASE 2
P(mm H2O) →
1600
800
0
Z (m) →
0
4
8
12
16
030602
020602
010602
040202
030202
020202
010202

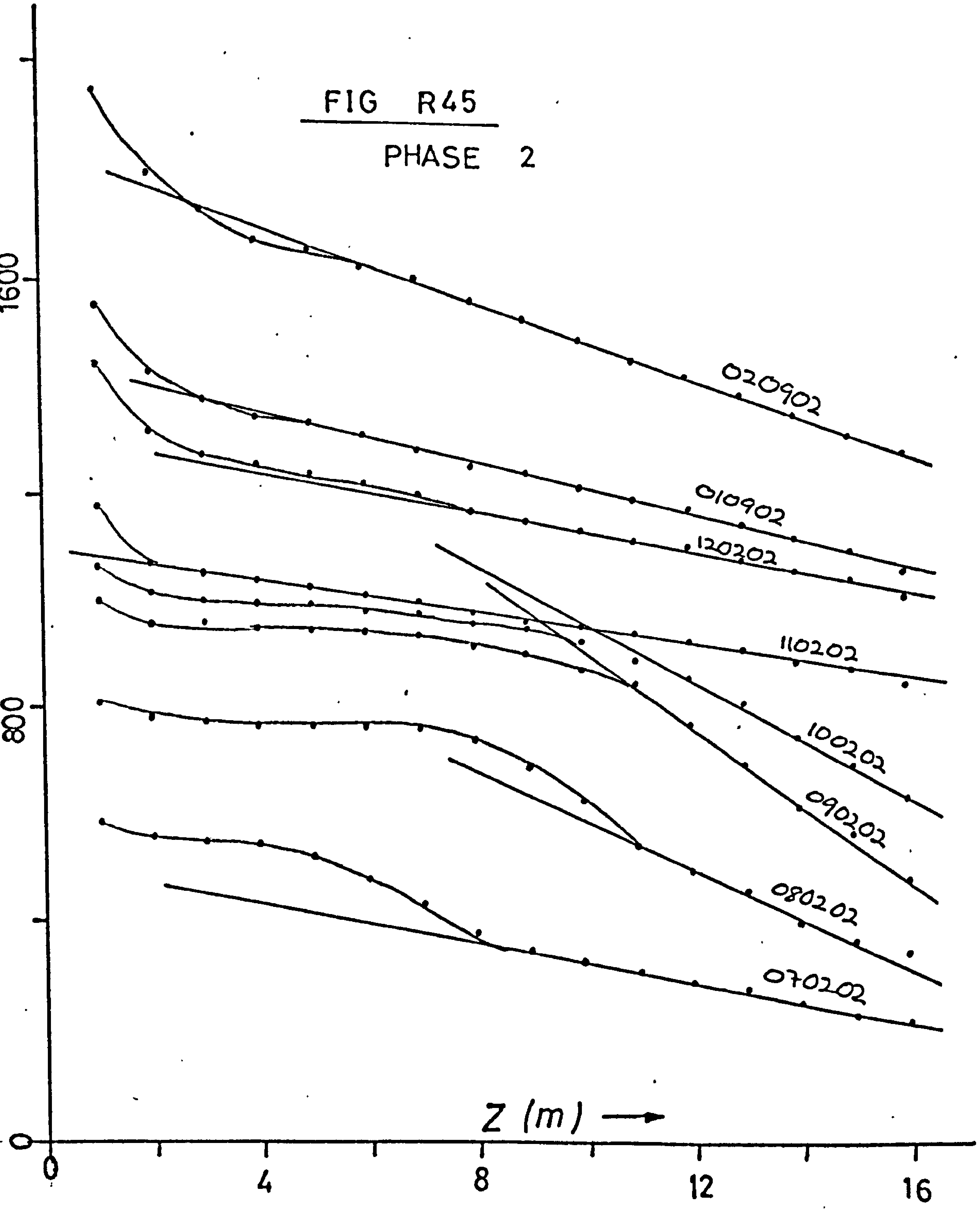


FIG R45
PHASE 2
P(mm H_2O) →
Z (m) →
1600
800
0
0
4
8
12
16
020902
010902
120202
110202
100202
090202
080202
070202

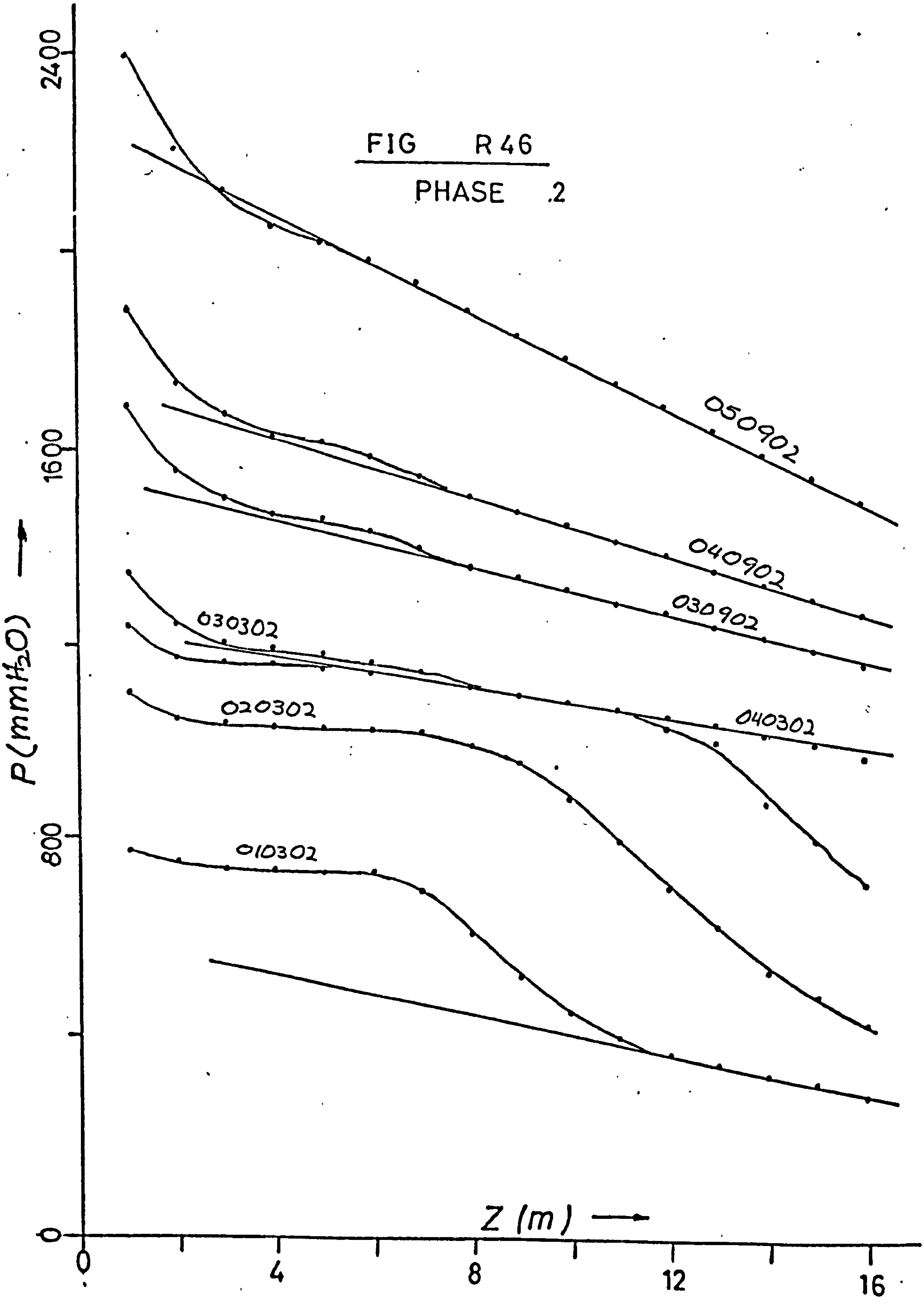
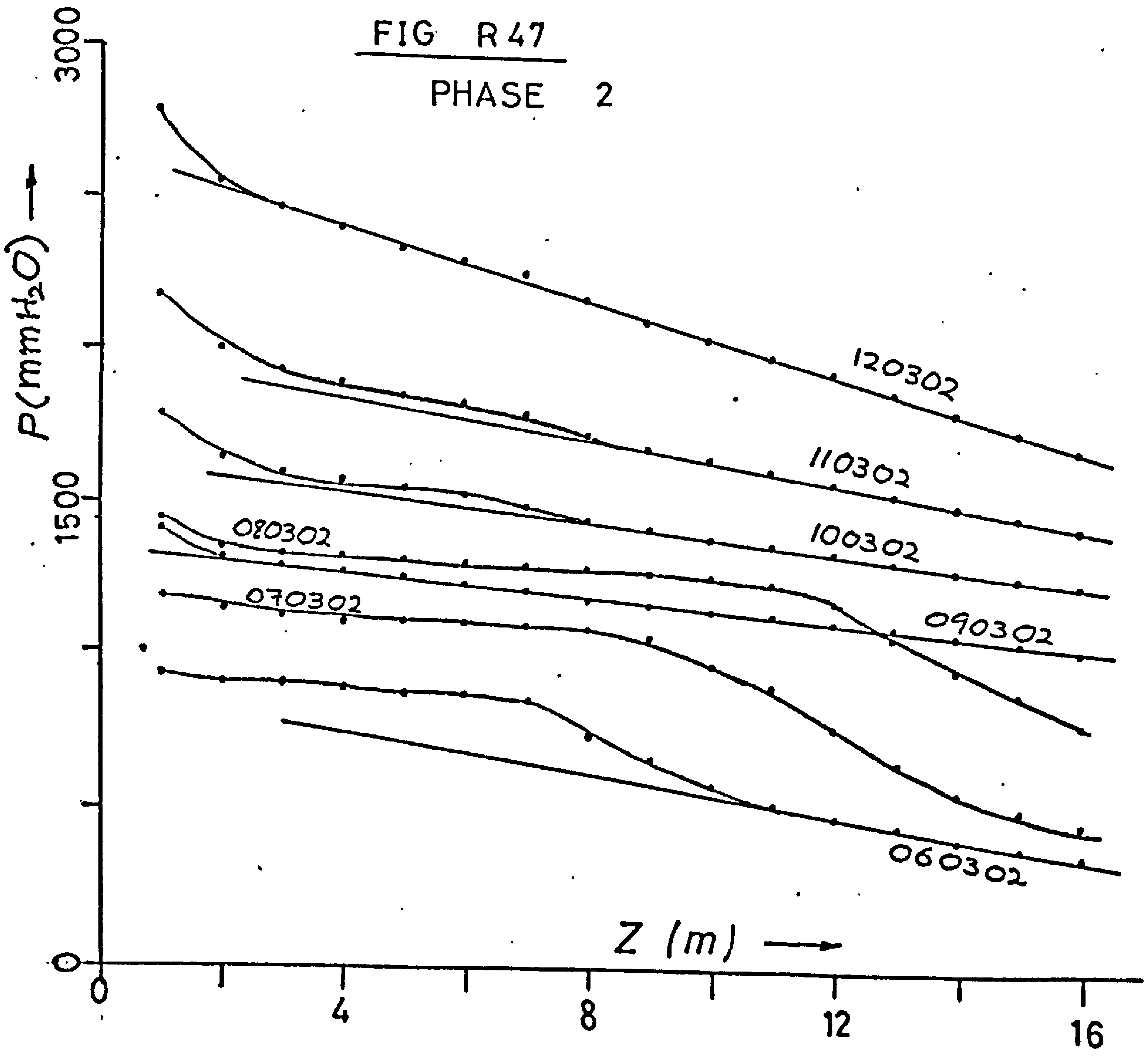


FIG R 46

PHASE .2

FIG R47

PHASE 2



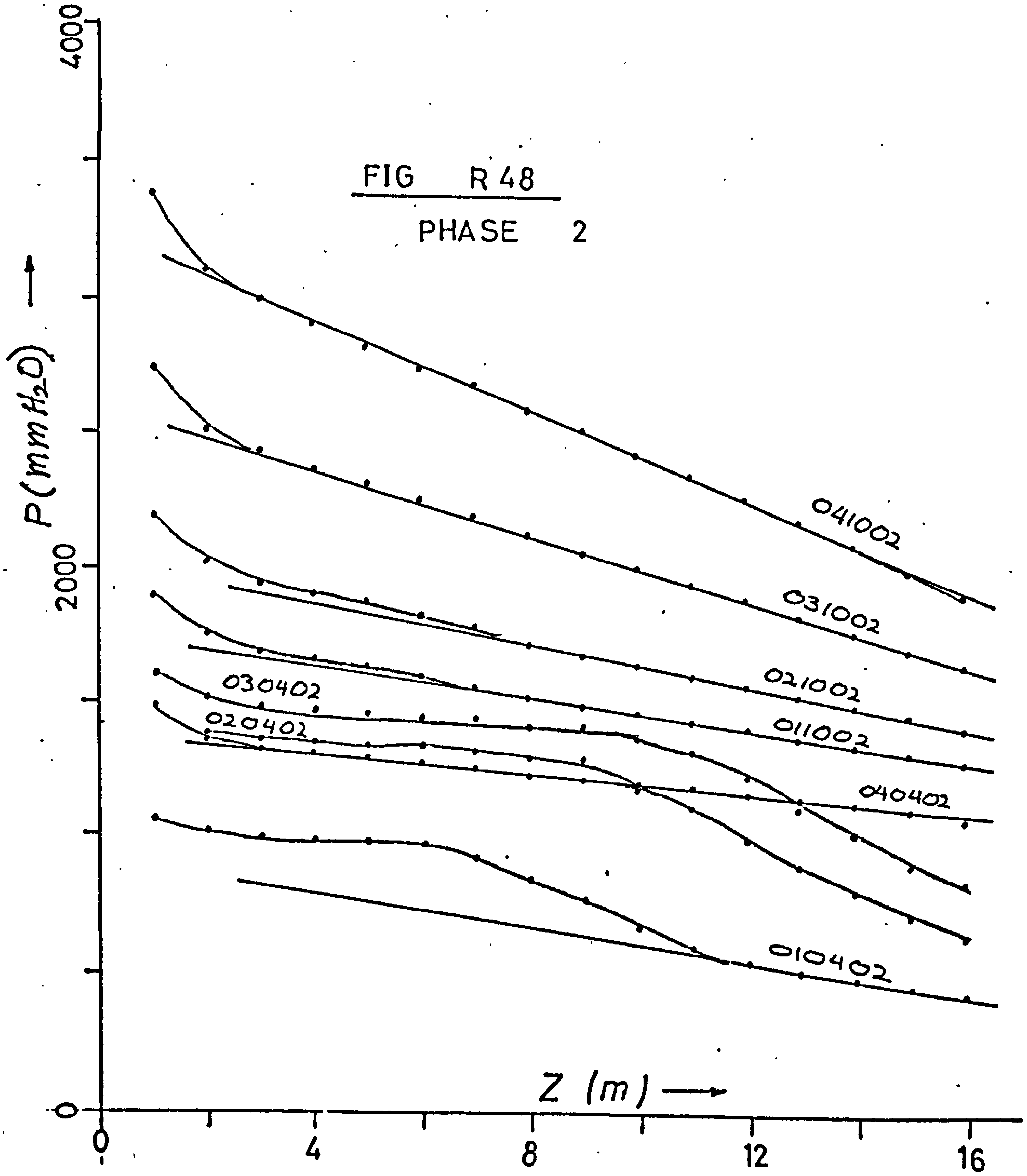


FIG R 48
PHASE 2
P (mm H₂O) →
4000
2000
0
Z (m) →
0
4
8
12
16
041002
031002
021002
011002
040402
030402
020402
010402

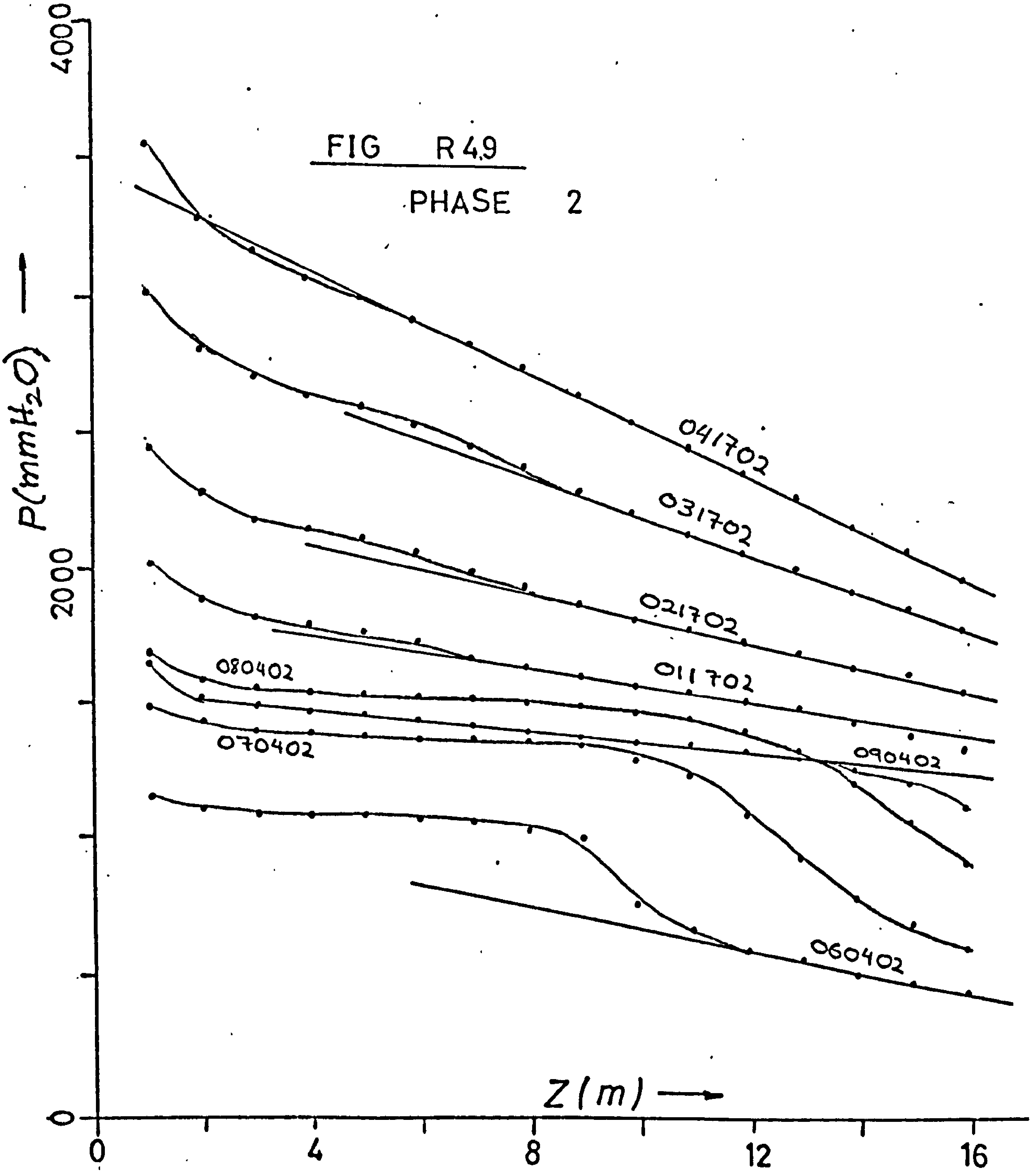


FIG R4.9

PHASE 2

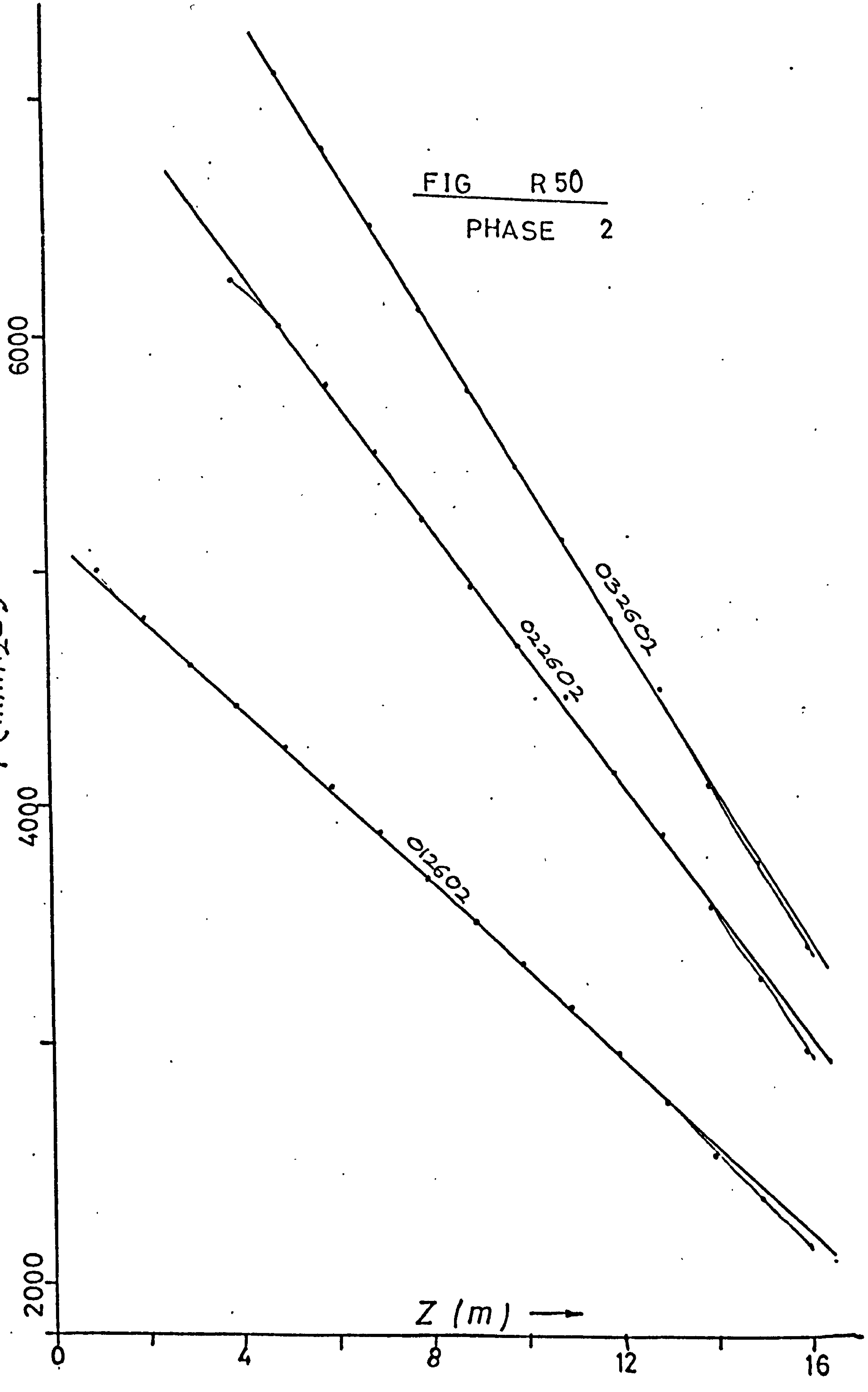


FIG R50

PHASE 2

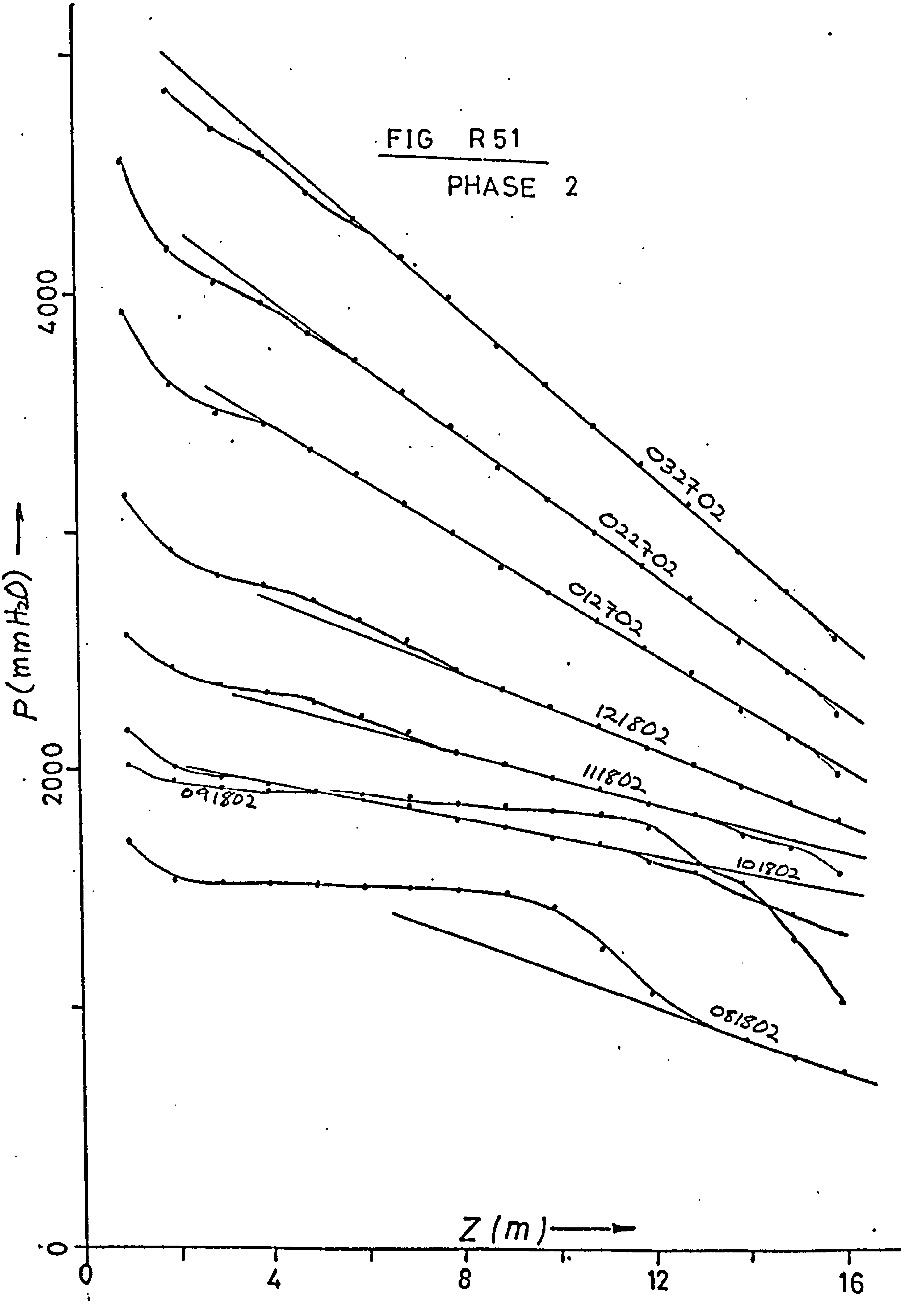
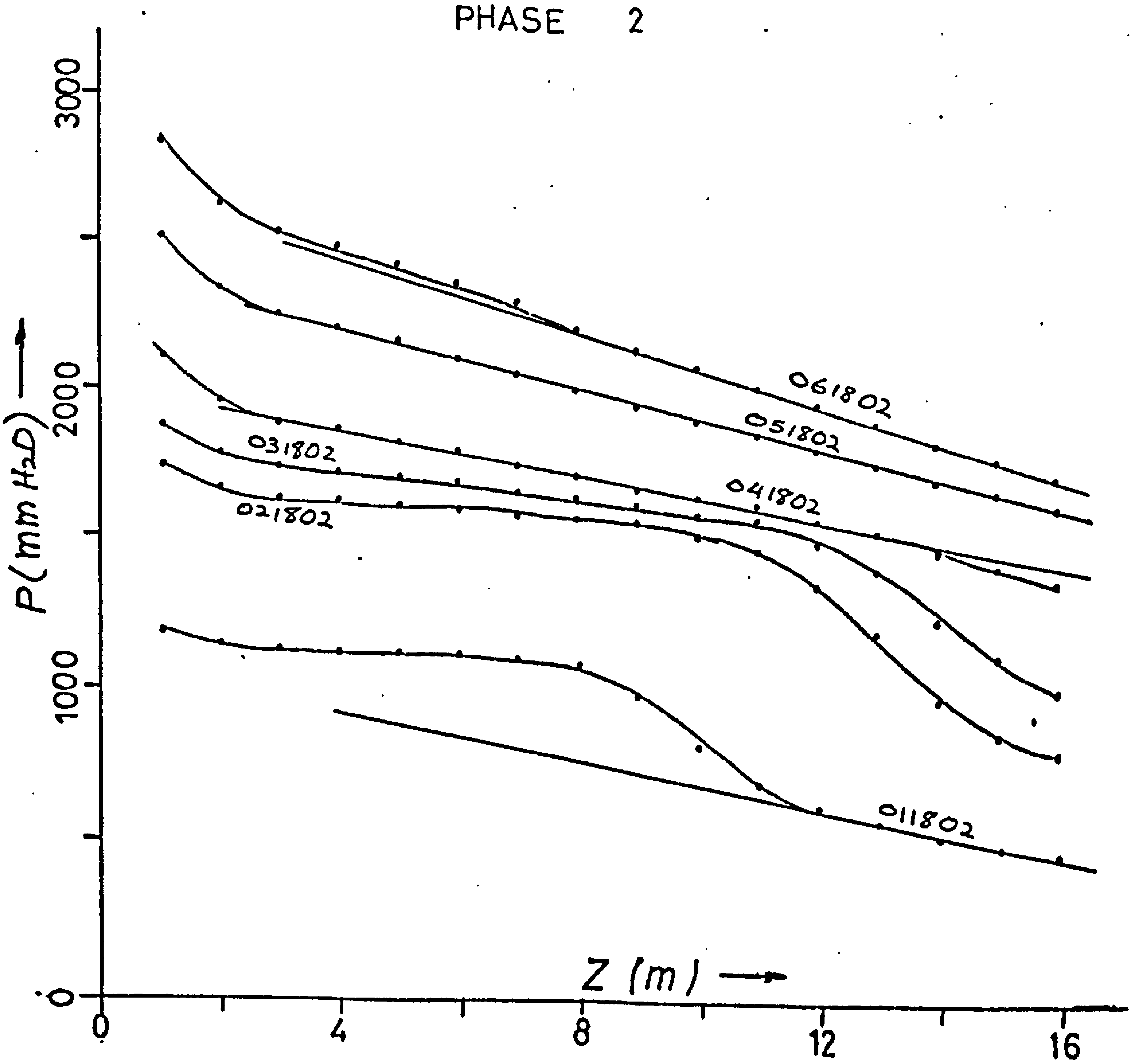


FIG R51
PHASE 2
P (mm H₂O) →
Z (m) →
4000
2000
0
0
4
8
12
16
032702
022702
012702
121802
111802
101802
091802
081802

FIG R52

PHASE 2



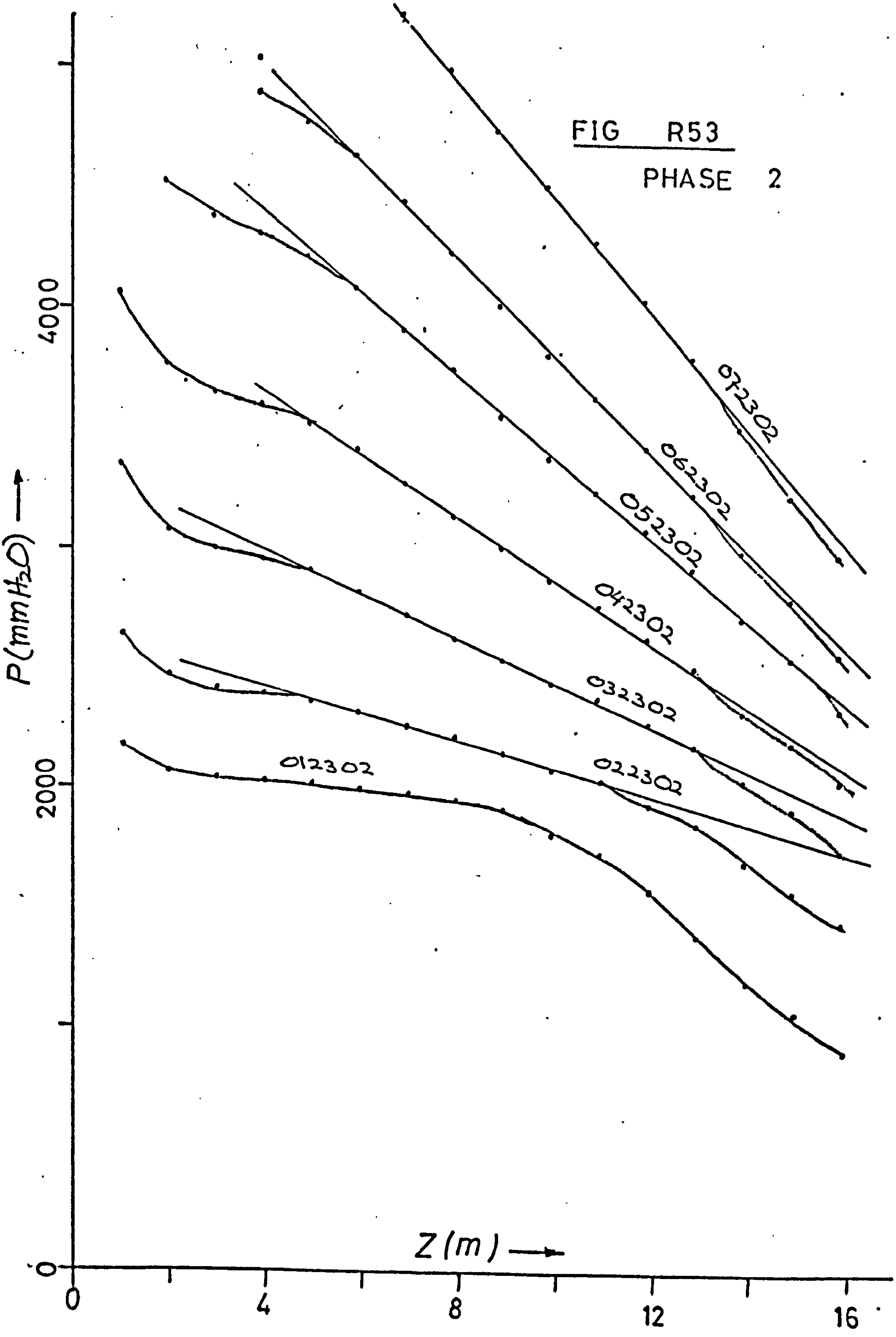


FIG R53

PHASE 2

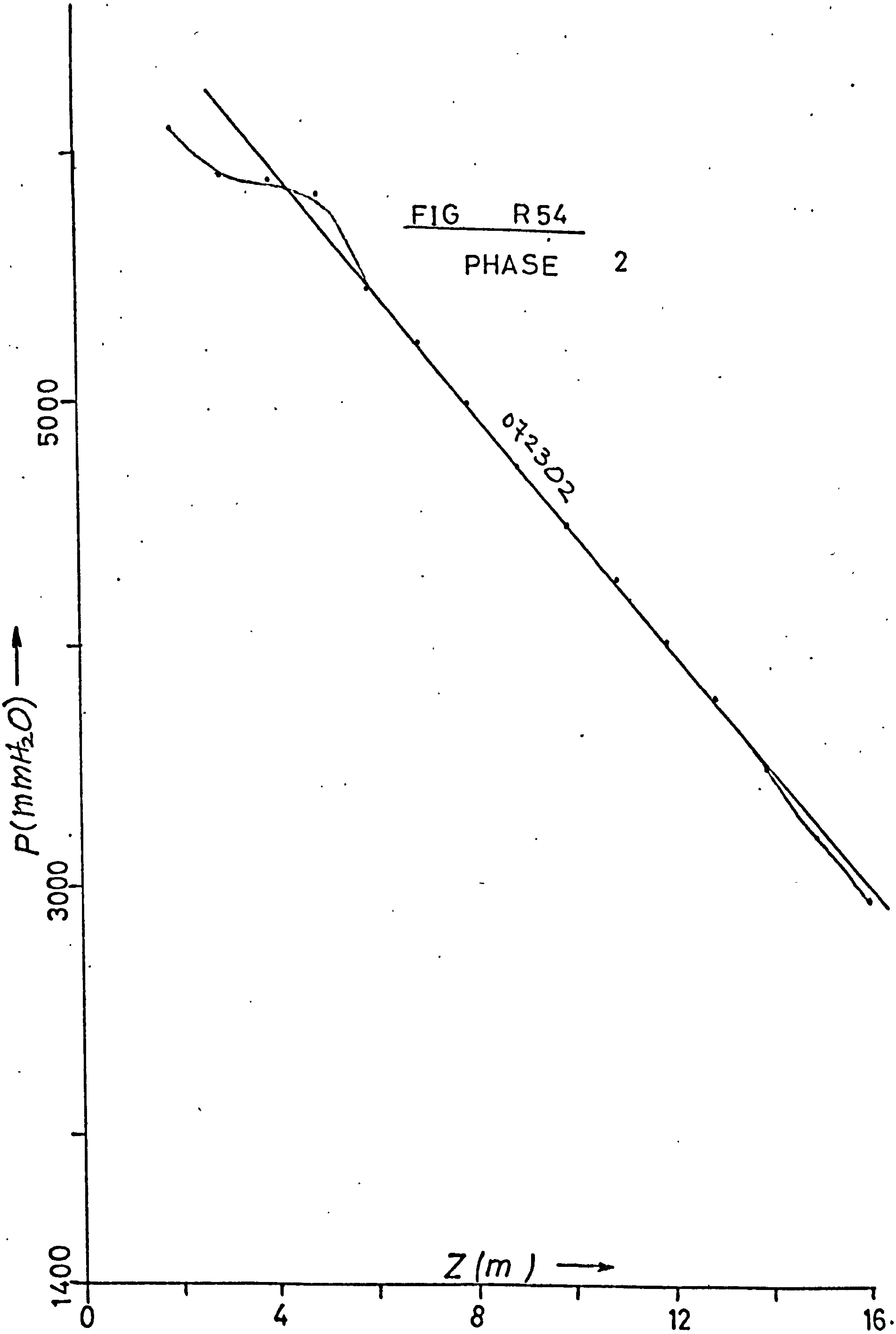


FIG R54
PHASE 2
072302
P(mmH2O) →
5000
3000
1400
Z (m) →
0
4
8
12
16

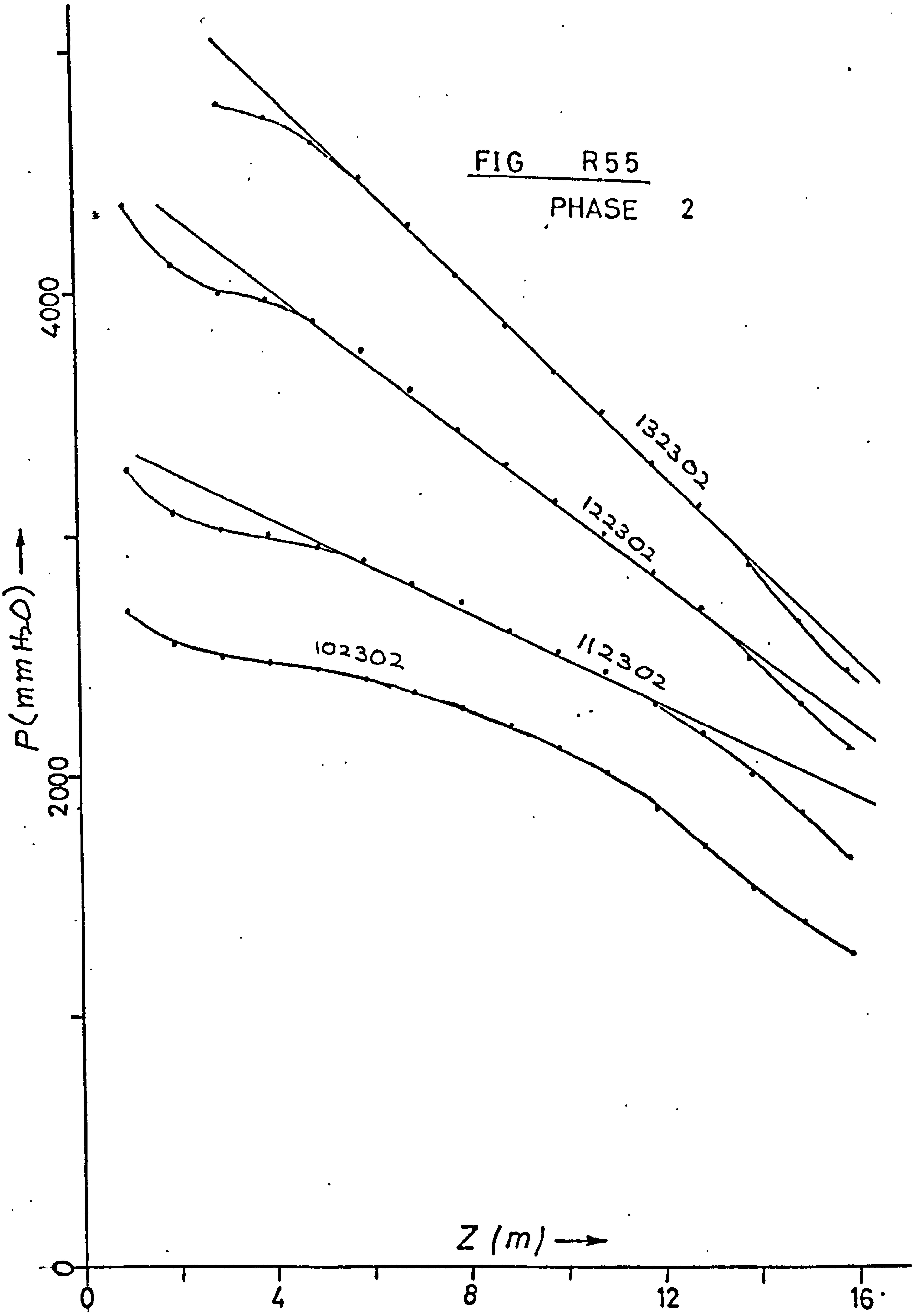


FIG R55
PHASE 2
132302
122302
112302
102302
P(mm H2O) →
4000
2000
0
Z (m) →
0
4
8
12
16

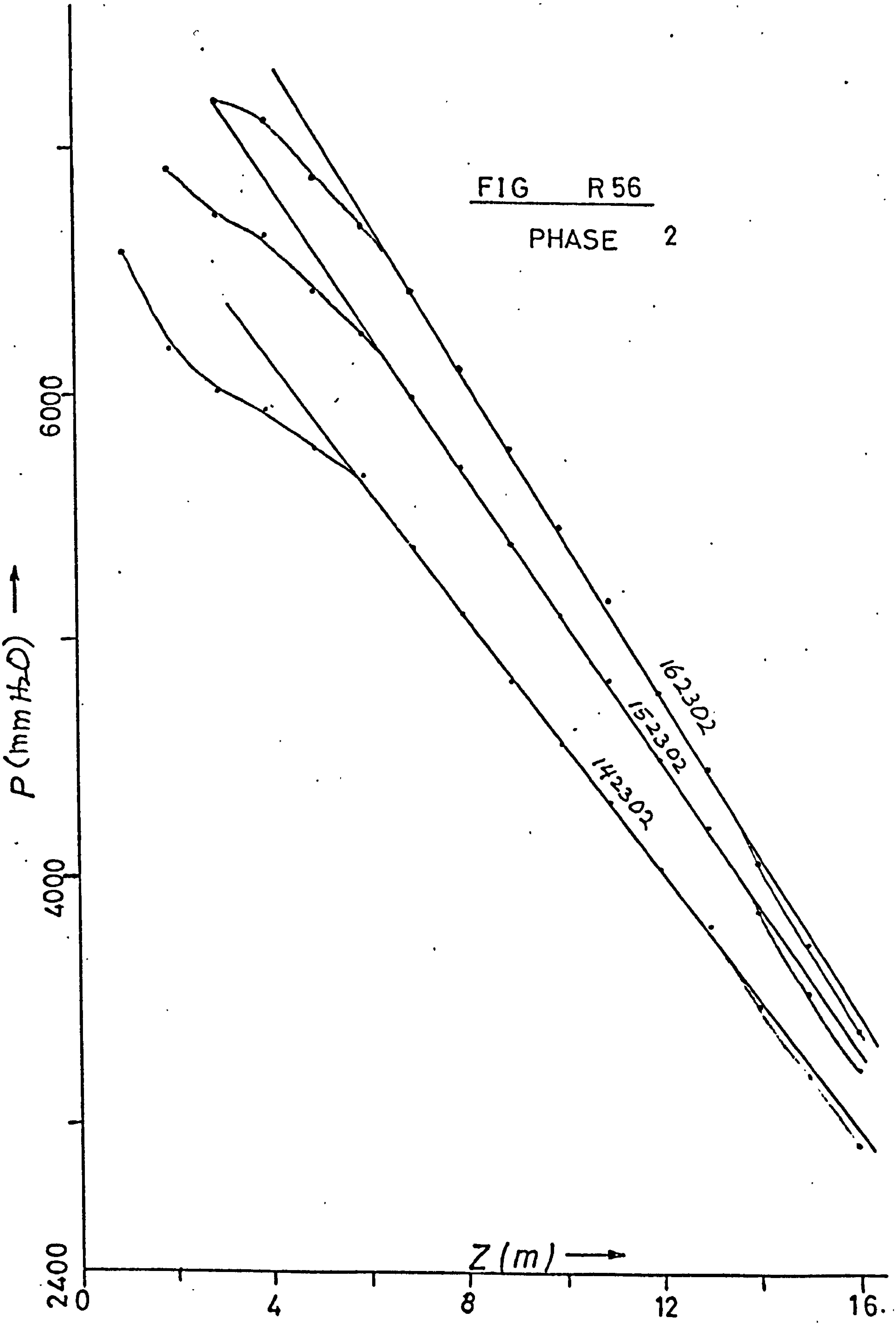


FIG R56

PHASE 2

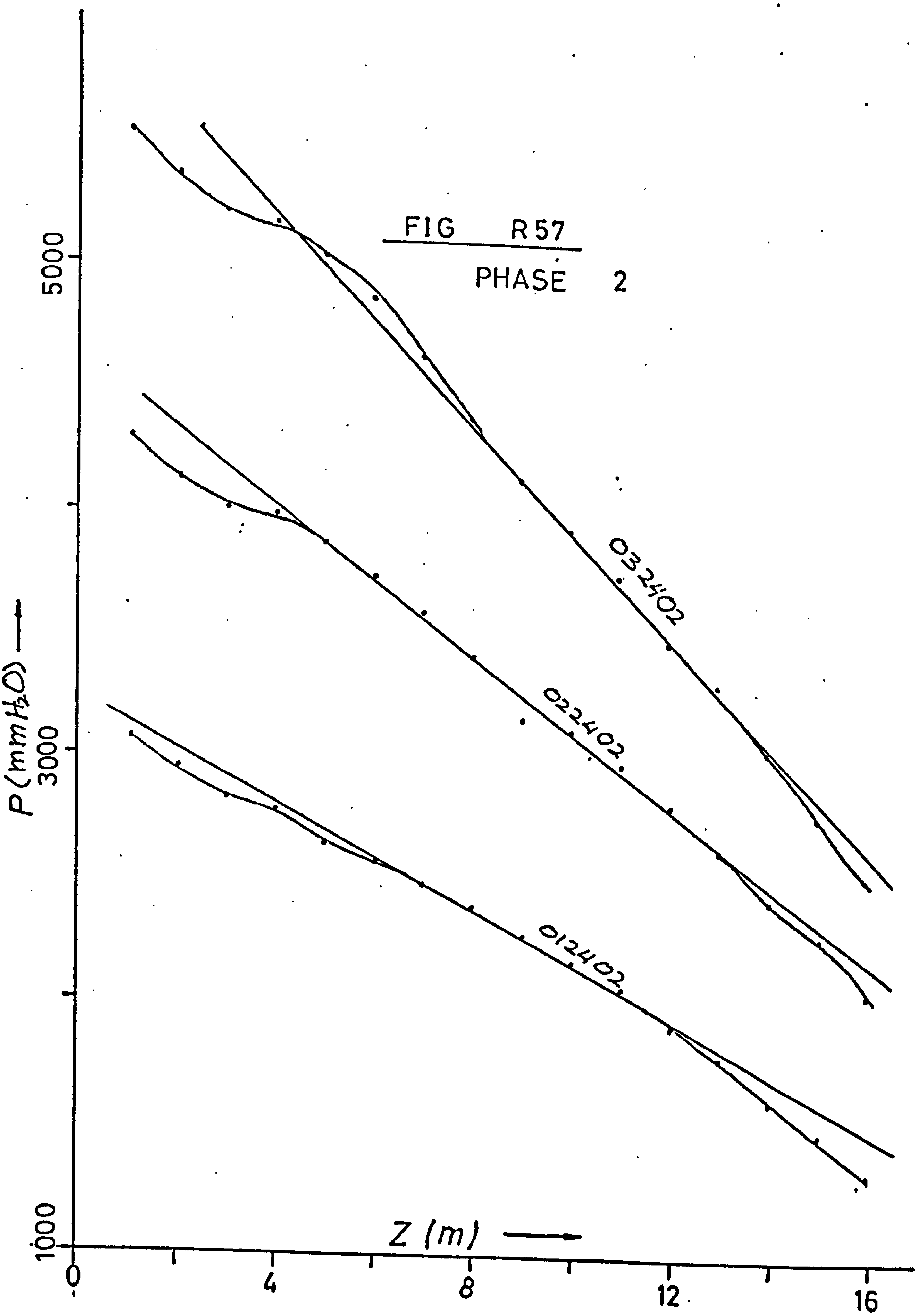


FIG R57
PHASE 2
5000
3000
1000
P (mm H₂O) →
Z (m) →
0
4
8
12
16
032402
022402
012402

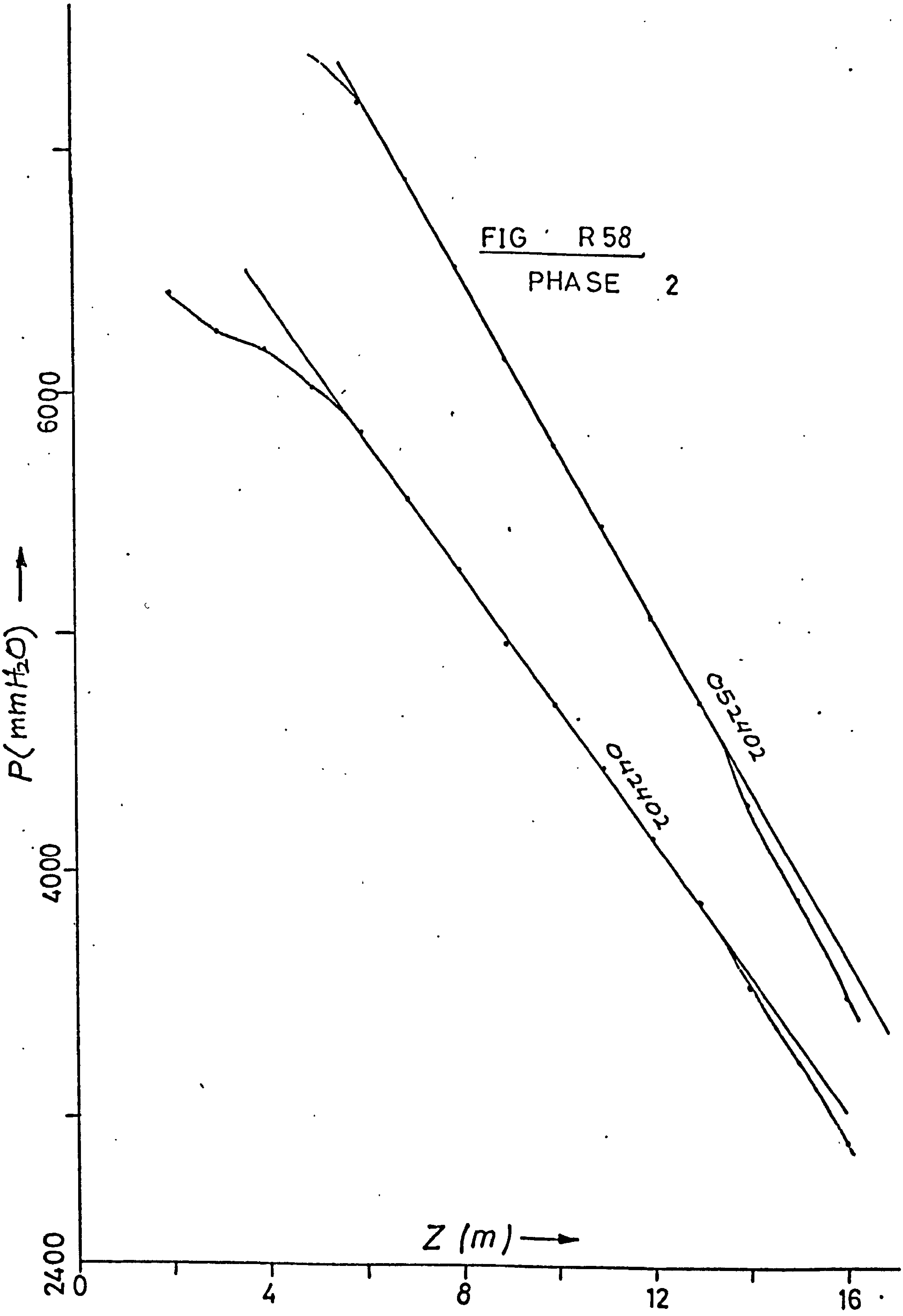


FIG R58

PHASE 2

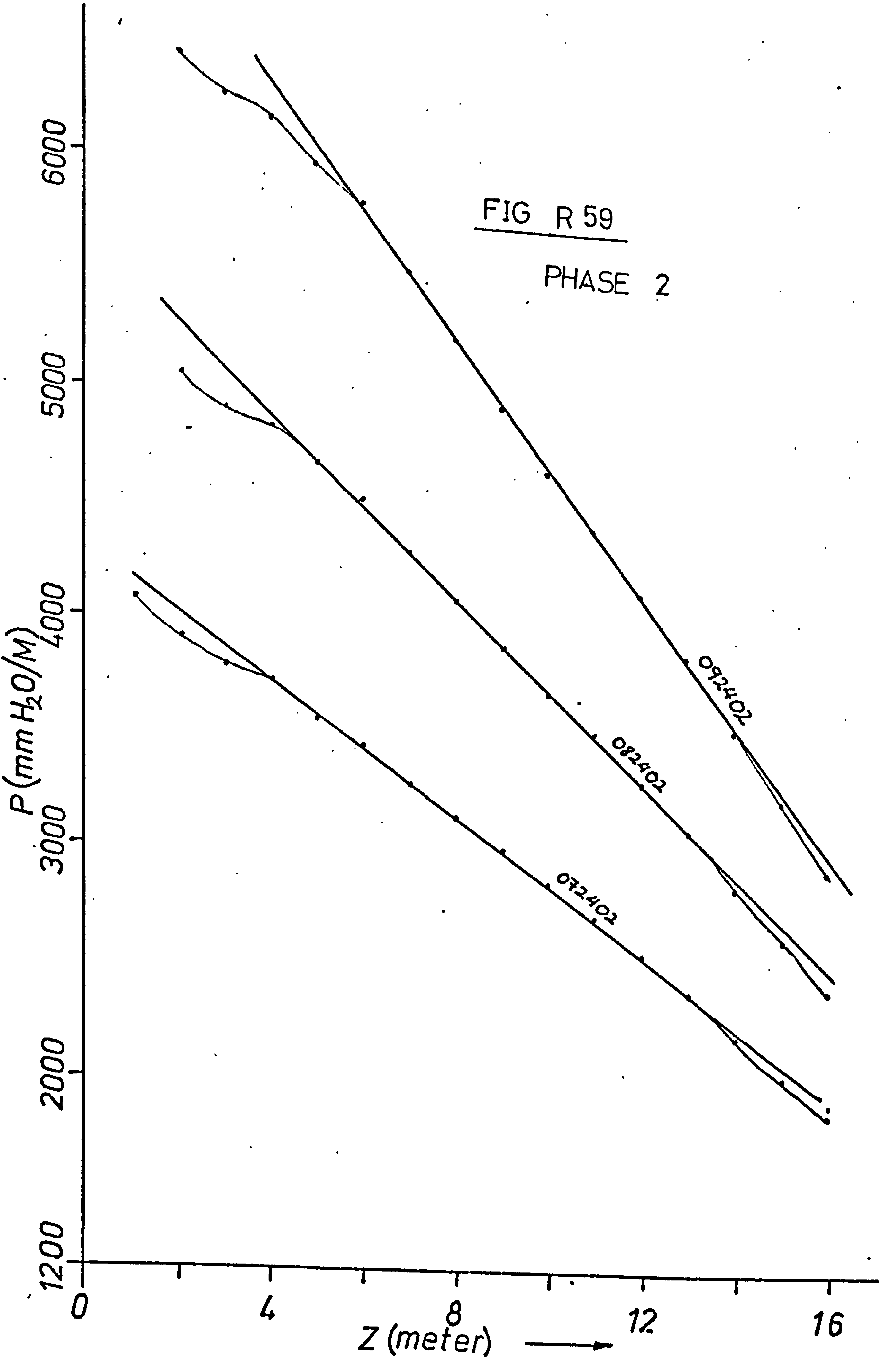


FIG R 59

PHASE 2

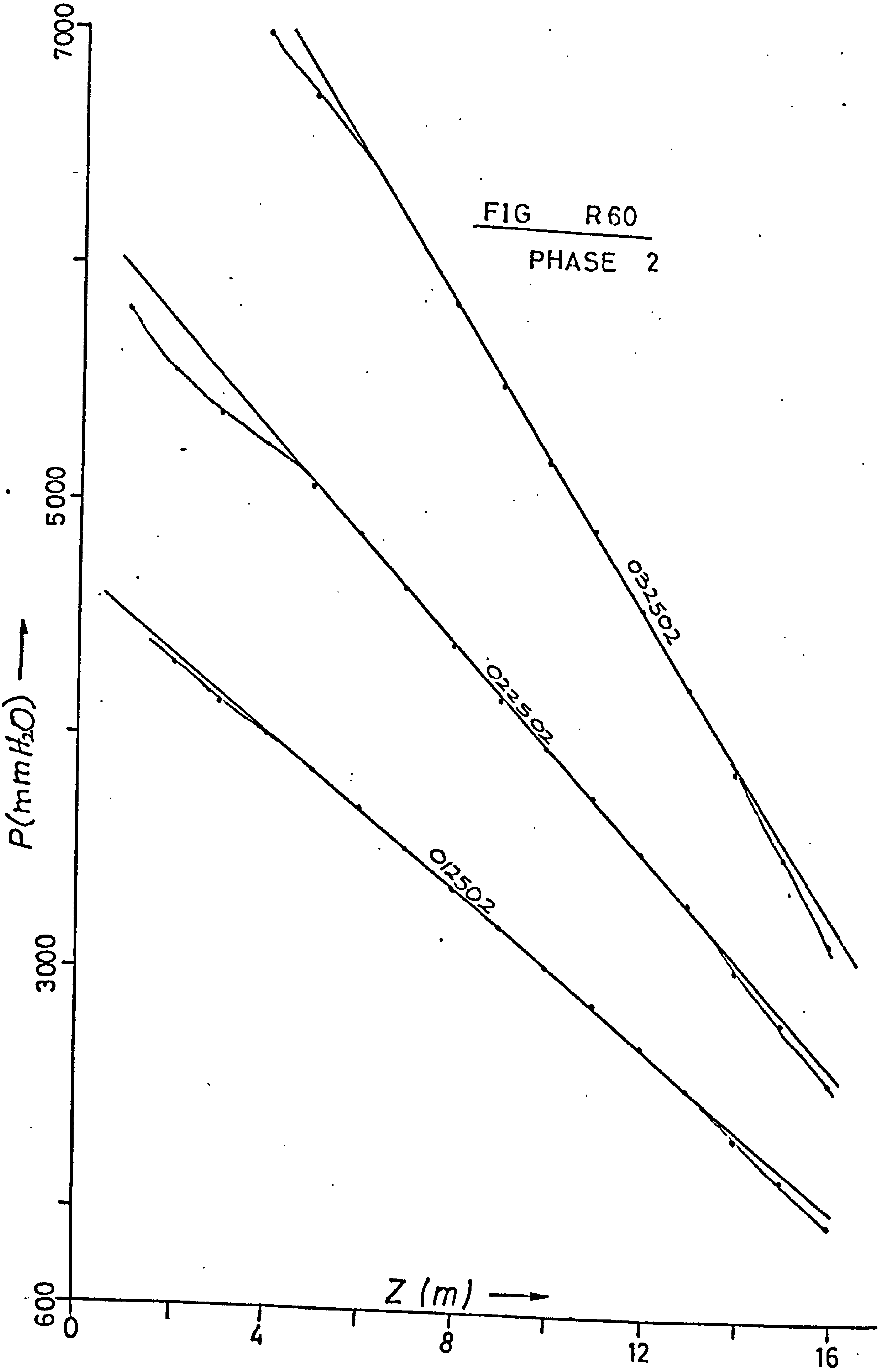


FIG R60

PHASE 2

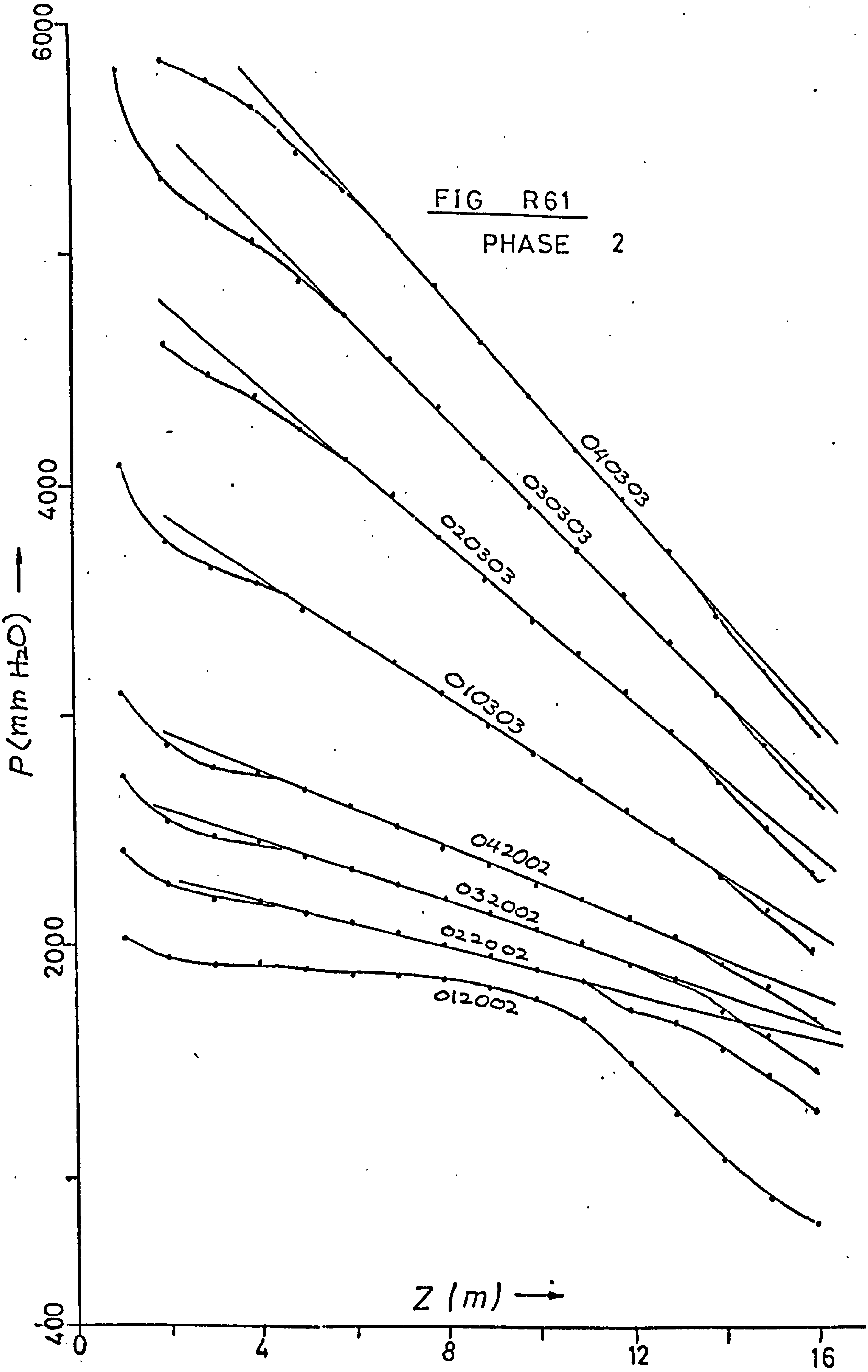


FIG R61

PHASE 2

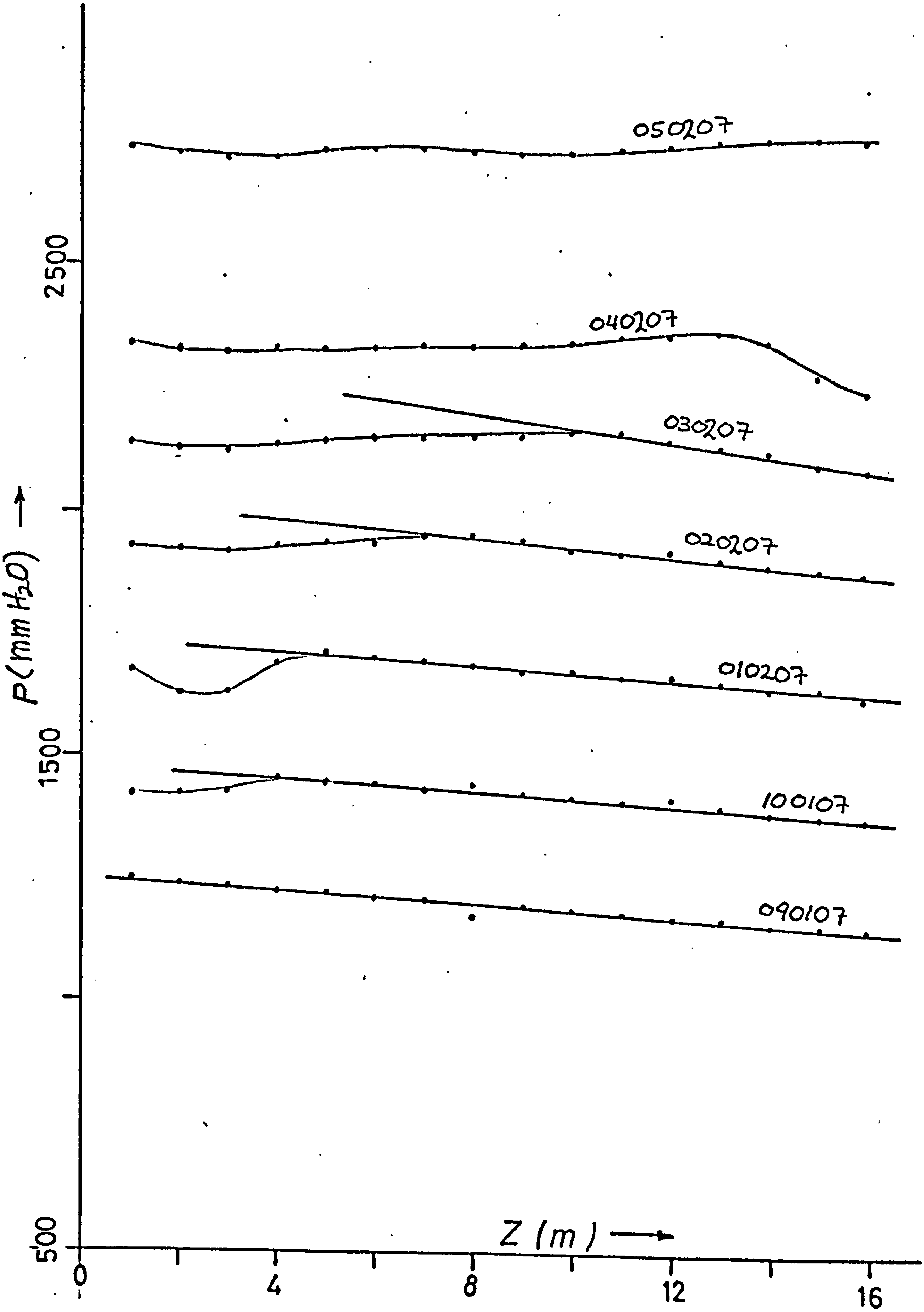


FIG R62

PHASE 3

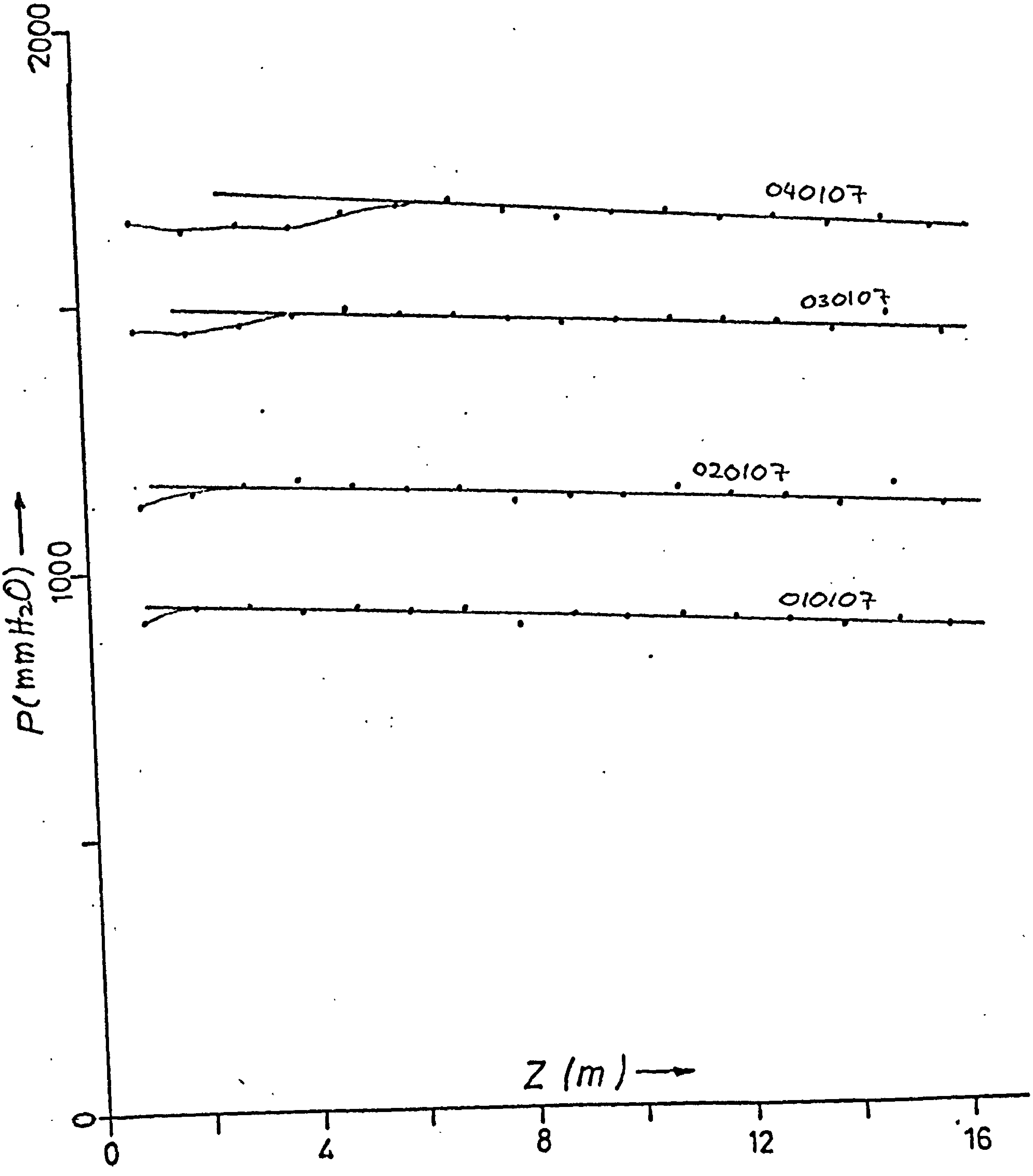


FIG R63

PHASE 3

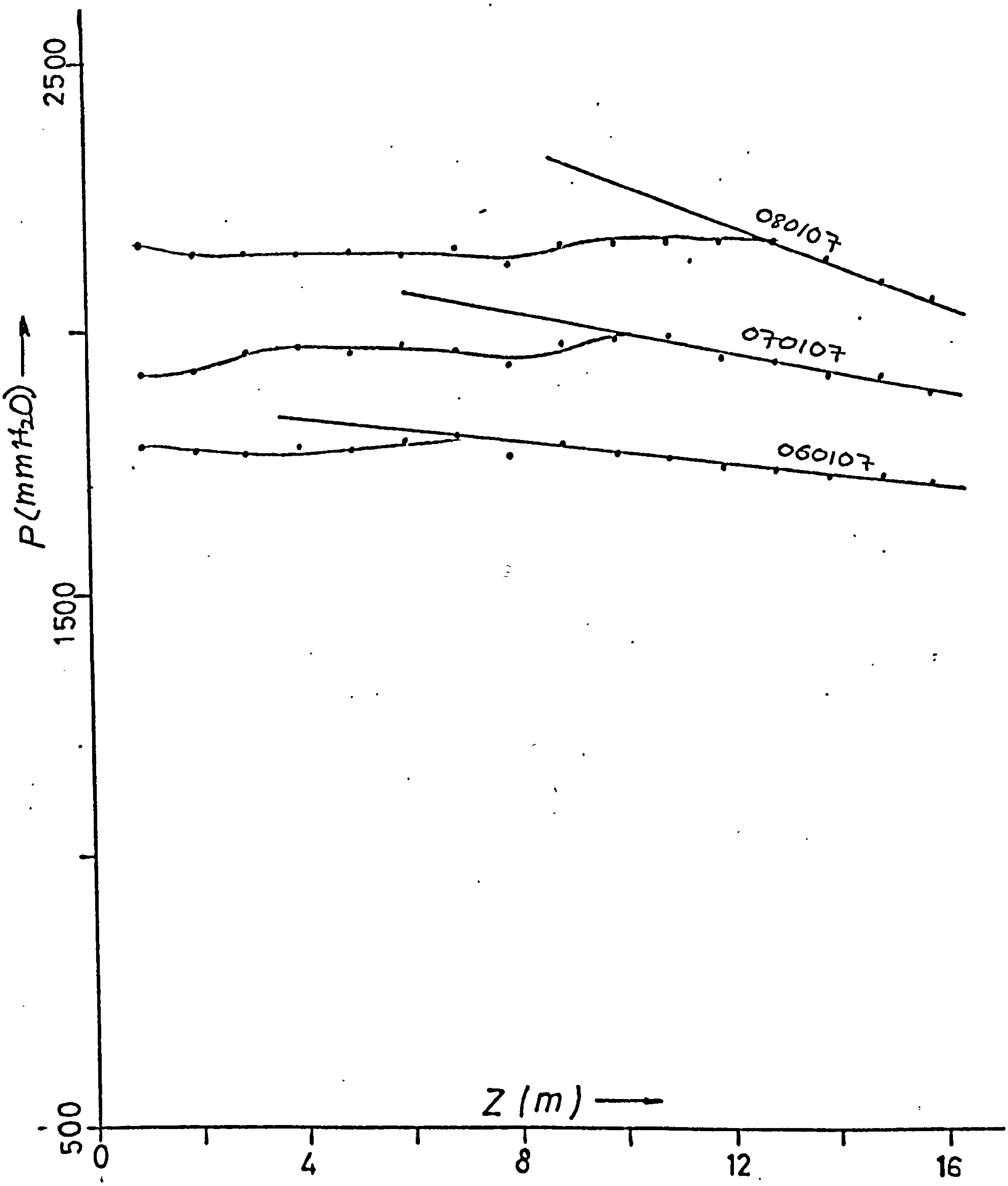


FIG R64

PHASE 3

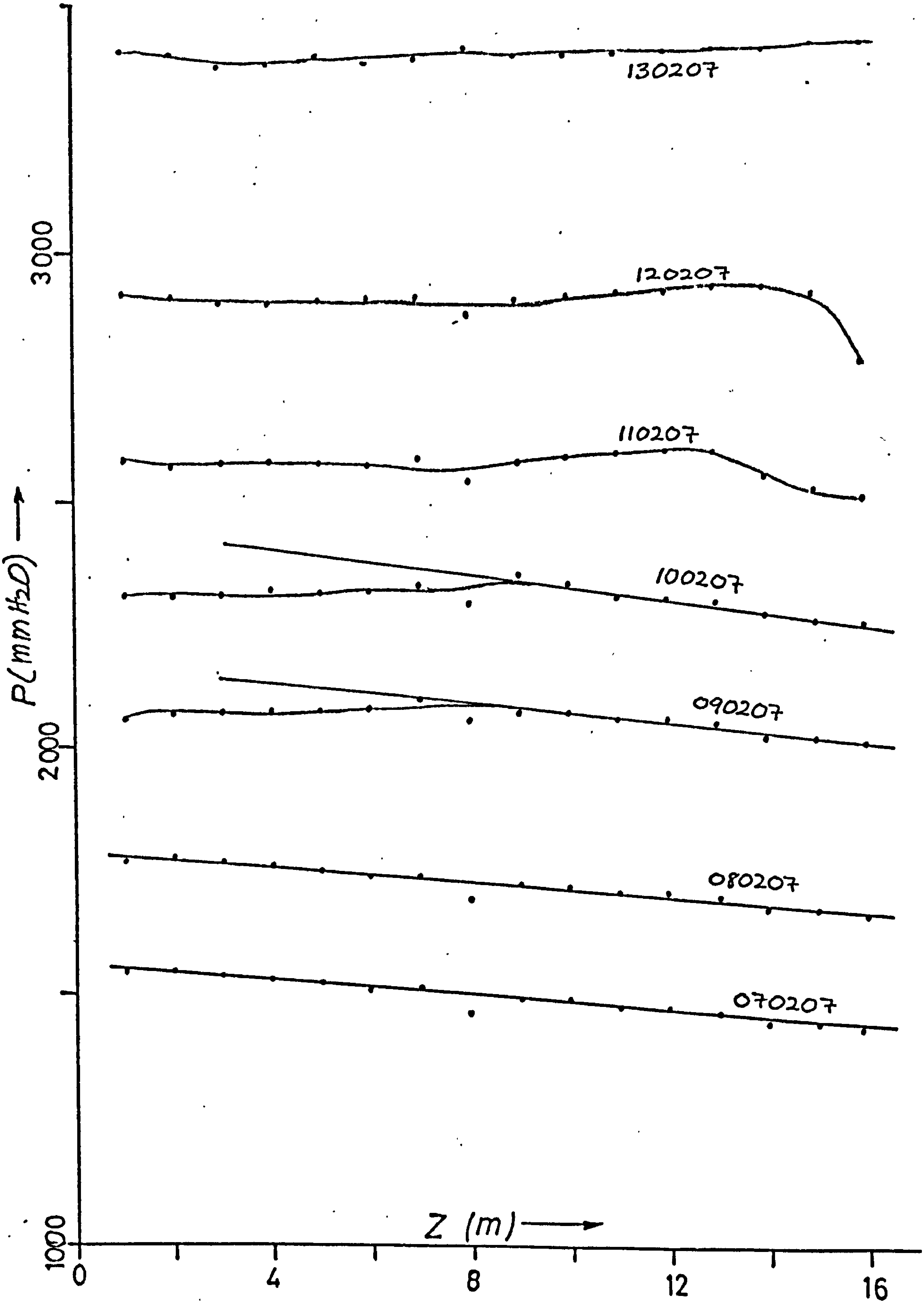


FIG R 65

PHASE 3

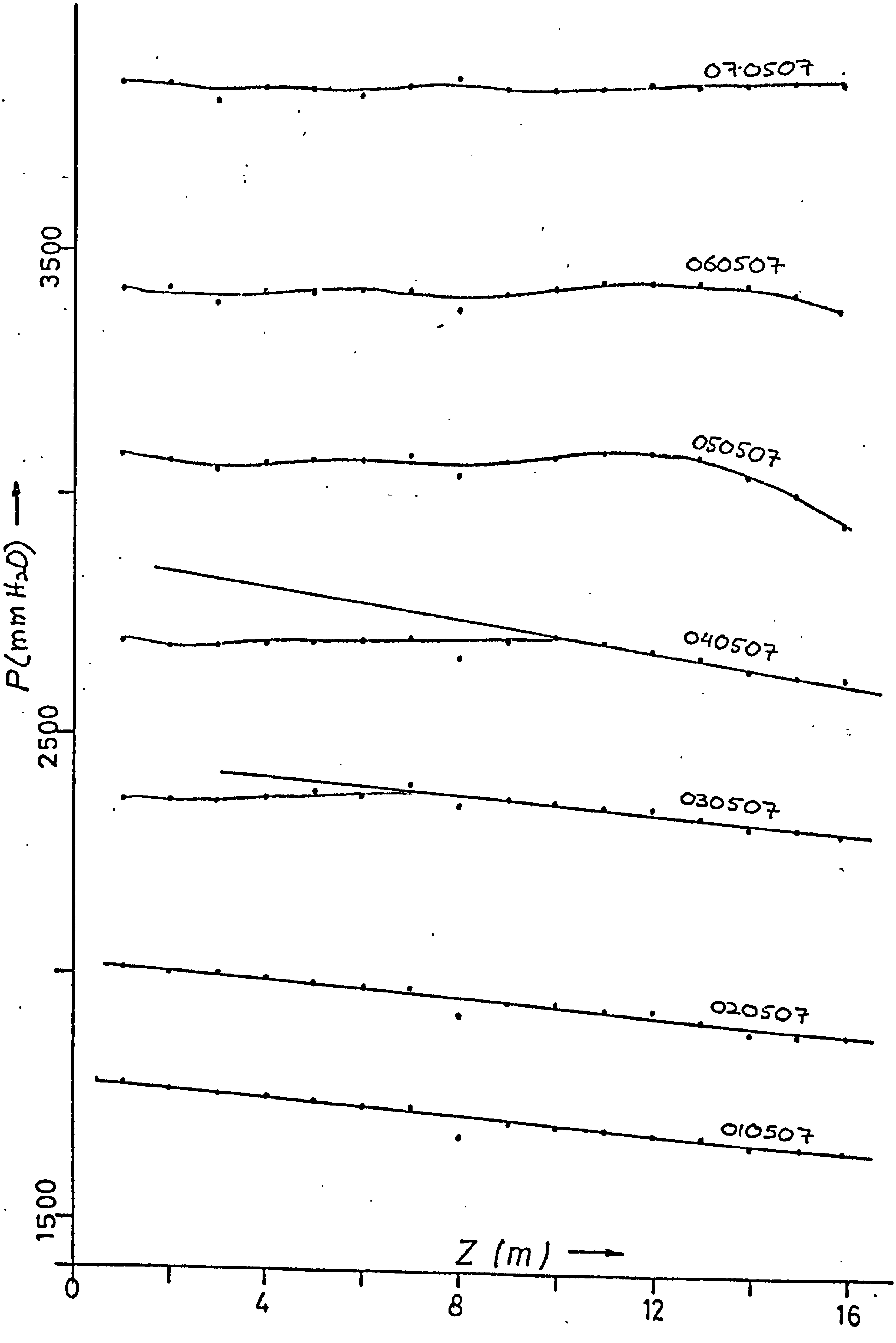


FIG R66

PHASE 3

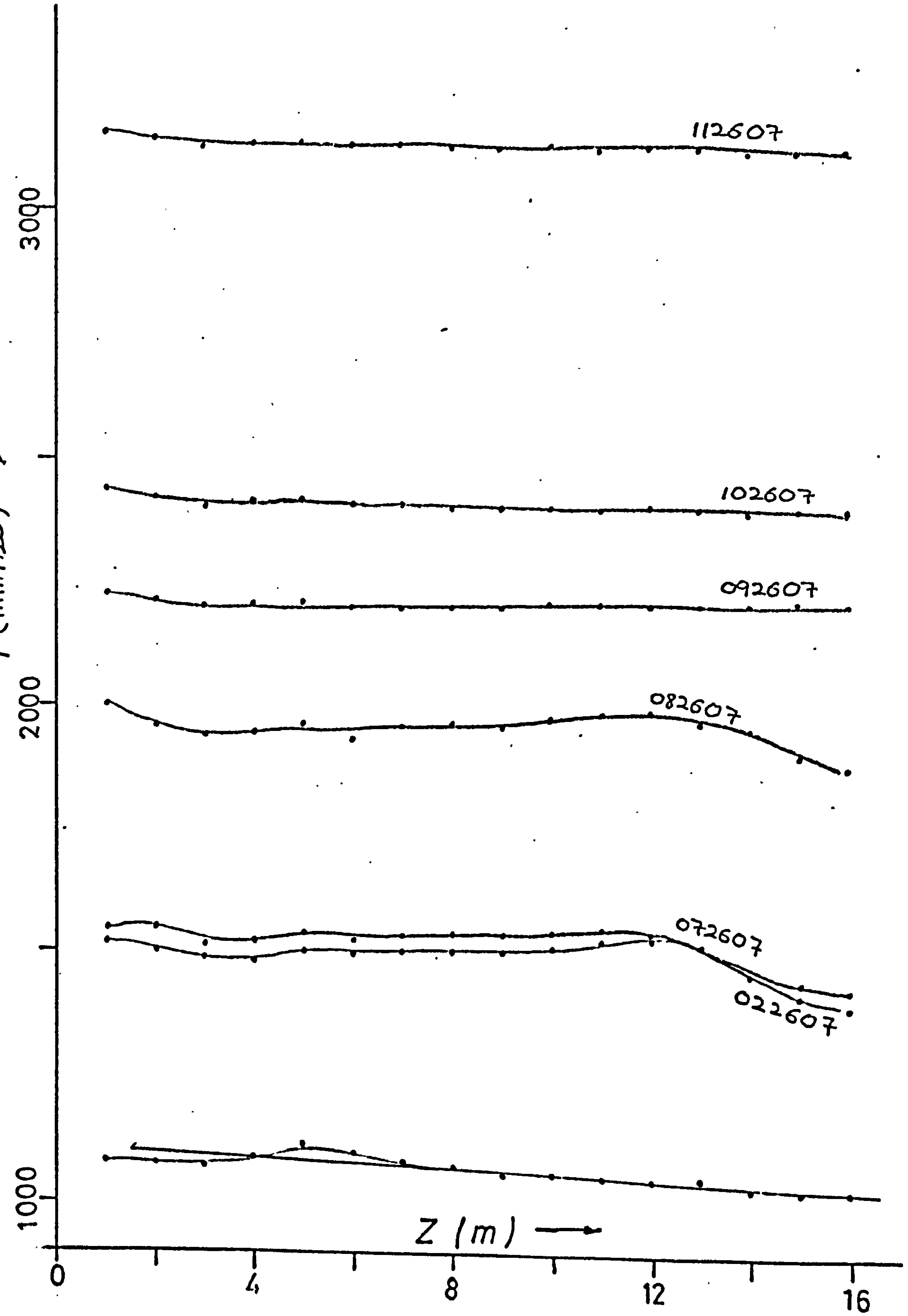
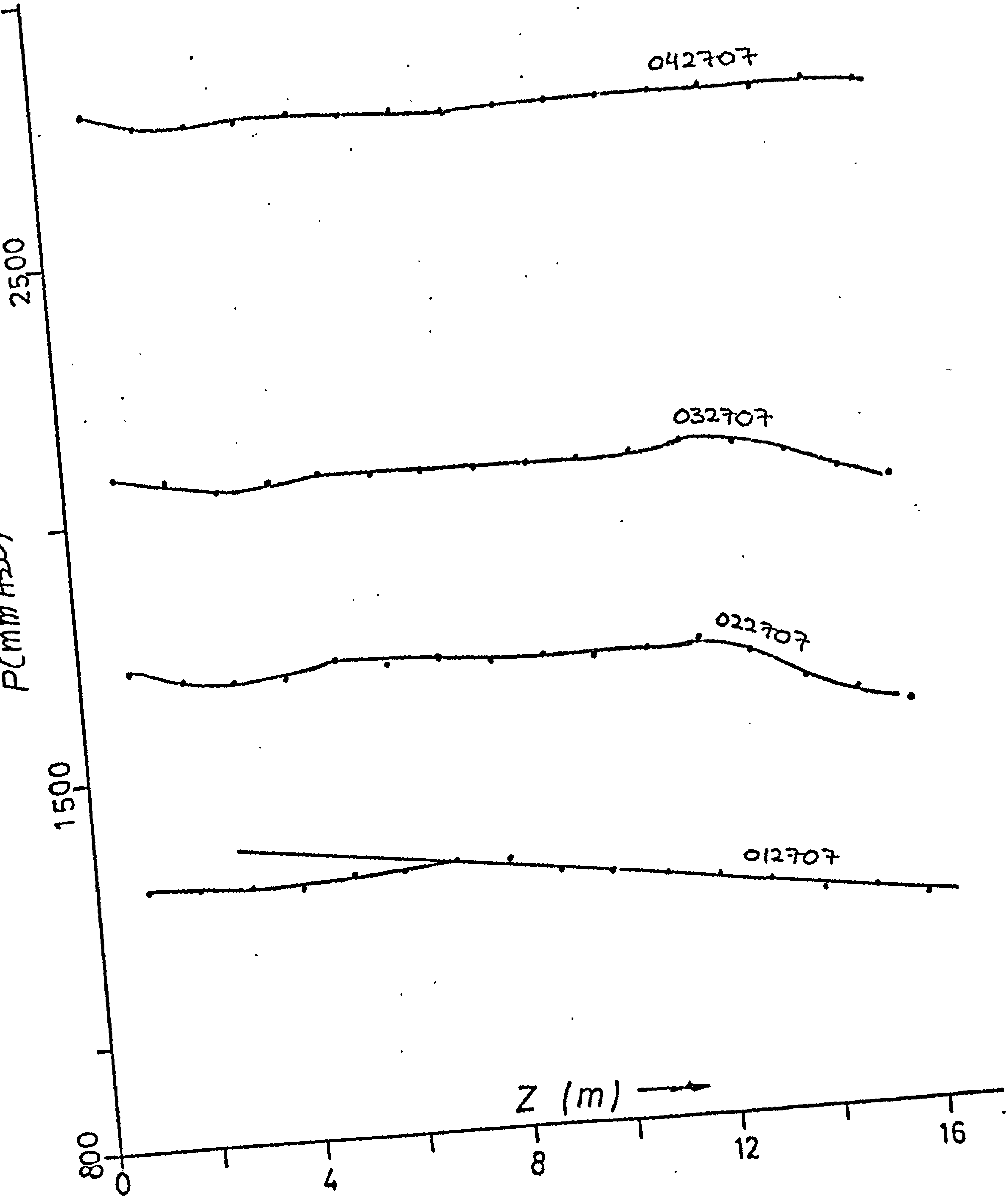


FIG R67

PHASE 3



PHASE 3

FIG R68

APPENDIX S

EXPERIMENTAL RESULTS FOR PHASES 1, 2 AND 3.

APPENDIX S EXPERIMENTAL RESULTS FOR PHASES 1, 2 AND 3

CONTENTS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	INLET L/D	OUTLET L	OUTLET L/D	METRE FLOW PATRN L	METRE FLOW PATRN L/D	PR-GRAD KN/M3	FLOW PATTERN
30807	21.0	102.58	0.047	0.018142	0.001828	998.02	1.2194	1.75	13.8	2.25	17.7	4	31.5	0.11621	6
40807	23.5	103.31	0.150	0.018012	0.003660	997.45	1.2176	1.25	9.8	2.25	17.7	8	63	0.12258	6
50807	25.0	103.73	0.267	0.018012	0.005949	997.07	1.2164	1.25	9.8	1.25	9.8	8	63	0.14269	2
60807	26.0	104.04	0.330	0.017882	0.008347	996.81	1.2160	3.25	25.6	1.25	9.8	8	63	0.16073	2
70807	27.2	104.38	0.377	0.017882	0.009822	996.48	1.2151	4.25	33.5	1.25	9.8	8	63	0.16750	2
80807	29.0	104.97	0.427	0.017882	0.012545	995.97	1.2147	3.25	25.6	1.25	9.8	6	47.2	0.18084	2
140807	19.5	105.46	0.456	0.018337	0.014331	998.34	1.2601	4.25	33.5	1.25	9.8	6	47.2	0.21751	2
150807	21.0	105.85	0.524	0.018337	0.016434	998.02	1.2582	4.25	33.5	4.75	37.4	6	47.2	0.23144	2
160807	23.5	106.30	0.563	0.018337	0.021324	997.45	1.2529	4.75	37.4	5.75	45.3	6	47.2	0.24909	2
170807	25.0	106.88	0.594	0.018270	0.026330	997.07	1.2533	2.25	17.7	2.25	17.7	8	63	0.27420	2
180807	26.5	107.02	0.618	0.018142	0.031833	996.67	1.2488	2.25	17.7	4.25	33.5	8	63	0.28802	2
190807	28.5	107.46	0.641	0.018142	0.036988	996.11	1.2456	4.75	37.4	5.25	41.3	9	70.9	0.30039	2
200807	29.0	108.03	0.653	0.018080	0.040964	995.97	1.2501	2.75	21.7	3.25	25.6	11	86.6	--	2

TABLE S1 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET		OUTLET		METRE FLOW PATRN		PR-GRAD KN/M3	FLOW PATTERN
								L	L/D	L	L/D	L	L/D		
210837	29.0	102.19	0.682	0.018080	0.044367	995.97	1.2519	2.75	21.7	3.25	25.6	11	86.6	0.31519	2
10907	20.0	103.55	0.061	0.024291	0.001810	998.23	1.2351	1.25	9.8	1.25	9.8	10	78.7	0.20015	6
20907	23.0	104.97	0.145	0.024291	0.003631	997.57	1.2394	1.25	9.8	3.25	25.6	10	78.7	0.20869	6
30907	24.5	105.57	0.214	0.024291	0.005489	997.20	1.2401	0.75	5.9	1.25	9.8	10	78.7	0.23752	6
40907	26.0	105.82	0.271	0.024291	0.007410	996.81	1.2368	0.75	5.9	1.75	13.8	11	86.6	0.24968	62
50907	27.0	106.08	0.313	0.024291	0.008583	996.54	1.2357	0.75	5.9	2.25	17.7	11	86.6	0.26527	62
60907	28.5	106.98	0.395	0.024291	0.012186	996.11	1.2400	1.25	9.8	4.75	37.4	10	78.7	0.29057	2
70907	30.0	107.70	0.456	0.024144	0.015614	995.67	1.2421	1.25	9.8	4.75	37.4	8	63	0.32303	2
120907	19.0	106.86	0.433	0.024322	0.016185	998.44	1.2789							--	2
130907	22.0	107.39	0.488	0.024194	0.019170	997.80	1.2721							--	2
140907	24.0	108.07	0.533	0.024144	0.022816	997.32	1.2716	3.25	25.6	2.25	17.7	10	78.7	0.40610	2
150907	26.0	108.55	0.561	0.024097	0.026843	996.81	1.2687	3.25	25.6	2.25	17.7	8	63	0.42365	2
160907	27.5	109.33	0.587	0.024000	0.032238	996.40	1.2714	8.25	65	1.25	9.8	8	63	0.51917	2

TABLE S2 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	INLET L/D	OUTLET L	OUTLET L/D	METRE FLOW PATRN L	METRE FLOW PATRN L/D	PR-GRAD KN/M3	FLOW PATTERN
170907	29.5	109.85	0.591	0.023902	0.035683	995.82	1.2690	6.75	53.2	2.25	17.7	11	86.6	0.50563	2
180907	30.5	110.85	0.604	0.024533	0.038851	995.52	1.2763	8.25	65	3.25	25.6	11	86.6	0.56241	2
190907	32.0	111.32	0.630	0.024483	0.042706	995.05	1.2754	8.25	65	2.25	17.7	11	86.6	0.58987	2
11007	19.5	104.31	0.059	0.029373	0.001887	998.34	1.2462	2.75	21.7	1.75	13.8	8	63	0.28243	6
21007	22.5	106.27	0.127	0.029293	0.003777	997.68	1.2568	2.25	17.7	1.25	9.8	10	78.7	0.29499	6
31007	24.5	107.06	0.212	0.029011	0.006287	997.20	1.2576	2.25	17.7	1.25	9.8	10	78.7	0.33254	62
41007	25.5	107.39	0.262	0.028930	0.008223	996.94	1.2572	5.25	41.3	1.75	13.8	10	78.7	0.35932	2
51007	27.0	108.08	0.330	0.028930	0.011061	996.54	1.2590	1.25	9.8	5.25	41.3	10	78.7	0.37893	2
61007	29.5	109.02	0.400	0.028725	0.015142	995.82	1.2595	7.25	57.1	1.25	9.8	8	63	0.45768	2
71007	33.0	109.61	0.453	0.028686	0.018239	994.72	1.2518	5.25	41.3	2.25	17.7	8	63	0.47739	2
101007	19.5	109.85	0.447	0.029411	0.020431	998.34	1.3124	5.25	41.3	3.25	25.6	8	63	0.53688	2
111007	23.0	110.81	0.506	0.029252	0.027576	997.37	1.3082	5.25	41.3	2.25	17.7	8	63	0.60566	2
121007	25.0	111.48	0.533	0.029172	0.031118	997.07	1.3073	6.25	49.2	2.25	17.7	10	78.3	0.65048	2

TABLE S3 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN	TEMP	P MEAN	VOID FRCTN	WATER FLOW RATE	AIR FLOW RATE	DENSITY WATER	DENSITY AIR	SETTLING LENGTH,L						PR-GRAD	FLOW
								INLET		OUTLET		METRE FLOW PATRN			
NO	C	KN/M2		M3/SEC	M3/SEC	KG/M3	KG/M3	L	L/D	L	L/D	L	L/D	KN/M3	PATTERN
131007	26.0	112.19	0.553	0.029091	0.034901	996.81	1.3113	7.25	57.1	2.25	17.7	8	63	0.68882	2
141007	28.0	112.90	0.574	0.028930	0.038899	996.26	1.3107	8.25	65	2.25	17.7	8	63	0.71099	2
151007	30.0	113.77	0.572	0.028807	0.042190	995.67	1.3121	8.25	65	2.25	17.7	8	63	0.78306	2
161007	31.5	110.87	0.504	0.029293	0.025275	995.20	1.2723							--	2
21107	20.0	104.45	0.045	0.033026	0.001854	998.23	1.2459	6.75	53.2	3.25	25.6	8	63	0.35383	6
31107	22.0	106.97	0.124	0.032850	0.004030	997.80	1.2673	7.25	57.1	3.25	25.6	9	70.9	0.38391	6
41107	24.0	107.93	0.206	0.032633	0.006517	997.32	1.2699	6.25	49.2	3.25	25.6	10	78.7	0.42149	62
51107	26.5	108.31	0.233	0.033168	0.007845	996.67	1.2637	6.75	53.2	3.25	25.6	8	63	0.44660	2
61107	28.0	108.98	0.293	0.033063	0.010222	996.26	1.2653	6.75	53.2	2.75	21.7	8	63	0.48553	2
71107	30.0	110.10	0.363	0.032813	0.014180	995.67	1.2698	6.75	53.2	3.25	25.6	9	70.9	0.54211	2
81107	31.5	110.98	0.422	0.032526	0.017917	995.20	1.2737	6.75	53.2	3.25	25.6	8	63	0.57987	2
101107	19.5	111.60	0.445	0.033026	0.022059	998.34	1.3334	7.25	57.1	3.25	25.6	–	–	0.68941	2
111107	21.0	112.25	0.464	0.032956	0.025601	998.02	1.3343	6.25	49.2	2.25	21.7	–	–	0.71491	2

TABLE S4 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET		OUTLET		METRE FLOW PATRN		PR-GRAD KN/M3	FLOW PATTERN
								L	L/D	L	L/D	L	L/D		
121107	23.0	112.79	0.495	0.032813	0.028884	997.57	1.3316	6.25	49.2	2.25	17.7	—	—	0.74992	2
131107	25.0	114.16	0.524	0.032598	0.035563	997.07	1.3388	7.75	61	4.25	33.5	—	—	0.80582	2
21707	19.0	106.22	0.049	0.037306	0.001824	998.46	1.2713	4.25	33.5	2.25	17.7	—	—	0.42747	6
31707	21.5	106.70	0.105	0.037211	0.003543	997.91	1.2662	4.25	33.5	2.25	17.7	8	63	0.44944	6
41707	24.5	108.04	0.150	0.037115	0.005565	997.20	1.2691	7.25	57.1	2.25	17.7	8	63	0.50151	62
51707	27.0	108.64	0.194	0.036989	0.007490	996.54	1.2655	7.75	61	2.25	17.7	8	63	0.53283	2
61707	29.0	109.46	0.253	0.035895	0.009801	995.97	1.2665	8.75	68.9	2.25	17.7	9	70.9	0.57487	2
71707	31.0	111.05	0.337	0.037022	0.014119	995.36	1.2736	7.75	61	2.25	17.7	10	78.7	0.54842	2
101707	20.0	111.88	0.363	0.037022	0.017345	998.23	1.3344	7.75	61	2.25	17.7	10	78.7	0.72383	2
111707	24.0	112.97	0.415	0.035701	0.021797	997.32	1.3292	8.75	68.9	2.25	17.7	11	86.6	0.78640	2
121707	26.0	113.90	0.435	0.037022	0.025089	996.81	1.3312	8.25	65	2.25	17.7	10	78.7	0.83475	2
131707	28.0	115.00	0.480	0.036701	0.030021	996.26	1.3351	7.25	57.1	2.25	17.7	10	78.7	0.94821	2
141707	30.0	115.77	0.498	0.035510	0.033637	995.57	1.3352	7.25	57.1	2.25	17.7	10	78.7	0.95213	2

TABLE S5 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	INLET L/D	OUTLET L	OUTLET L/D	METRE FLOW PATRN L	L/D	PR-GRAD KN/M3	FLOW PATTERN
151707	31.5	117.41	0.518	0.036989	0.038484	995.20	1.3474	7.25	57.1	4.25	33.5	—	—	0.99146	2
32307	20.0	106.79	0.047	0.039657	0.001756	998.23	1.2737	1.75	13.8	1.25	9.8	5	39.4	0.48229	16
42307	23.0	107.43	0.110	0.039508	0.003838	997.57	1.2684	4.75	37.4	2.25	17.7	14	110.2	0.50612	26
52307	25.0	108.62	0.169	0.039361	0.005608	997.07	1.2738	5.25	41.3	1.25	9.8	8	63	0.54780	2
62307	27.5	109.30	0.193	0.039539	0.007416	996.40	1.2711	8.25	65	1.25	9.8	8	63	0.60409	2
72307	29.0	110.42	0.254	0.039421	0.009902	995.97	1.2777	7.25	57.1	0	0	8	63	0.63636	2
82307	31.0	111.85	0.321	0.039211	0.013599	995.36	1.2857	4.25	33.5	0	0	9	70.9	0.70579	2
112307	20.0	113.00	0.363	0.039954	0.016721	998.23	1.3477	7.75	61	0	0	9	70.9	0.81474	2
122307	23.0	114.14	0.405	0.039657	0.020836	997.57	1.3476	7.75	61	0.5	3.9	9	70.9	0.87280	2
132307	27.0	115.13	0.418	0.039480	0.024167	996.54	1.3411	7.25	57.1	1.0	7.9	10	78.7	0.90594	2
142307	29.0	116.47	0.452	0.039775	0.028541	995.97	1.3477	8.25	65	1.0	7.9	10	78.7	0.99148	2
152307	31.5	117.65	0.487	0.039480	0.033279	995.20	1.3502	7.75	61	0.5	3.9	10	78.7	1.07285	2
162307	33.0	118.14	0.501	0.039449	0.035084	994.72	1.3492	7.75	61	1.0	7.9	10	78.7	1.08364	2

TABLE S6 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	L/D	OUTLET L	L/D	METRE FLOW PATRN L	L/D	PR-GRAD KN/M3	FLOW PATTERN
12407	20.0	107.36	0.049	0.042683	0.001746	998.23	1.2805	2.25	17.7	1.25	9.8	6	47.2	0.47553	16
22407	22.0	107.75	0.097	0.042628	0.003509	997.80	1.2764	5.25	41.3	1.75	13.8	8	63	0.56732	62
32407	25.0	108.89	0.155	0.042573	0.005151	997.07	1.2769	6.75	53.2	1.75	13.8	9	70.9	0.61851	2
42407	27.0	109.85	0.220	0.042628	0.006883	996.54	1.2796	4.25	33.5	1.75	13.8	10	78.7	0.63410	2
72407	19.0	111.47	0.224	0.042850	0.010051	998.46	1.3341	5.25	41.3	1.25	9.8	10	78.7	0.73933	2
82407	21.5	112.50	0.298	0.042408	0.013447	997.91	1.3349	8.25	65	4.25	33.5	10	78.7	--	2
92407	23.0	113.95	0.341	0.042158	0.016983	997.57	1.3453	4.25	33.5	2.25	17.7	10	78.7	0.86407	2
102407	25.0	115.18	0.376	0.042379	0.020096	997.07	1.3507	7.75	61	2.25	17.7	10	78.7	0.95096	2
112407	27.0	116.46	0.410	0.042213	0.023824	996.54	1.3566	6.75	53.2	2.25	17.7	10	78.7	0.99440	2
122407	29.0	118.03	0.437	0.042434	0.028863	995.97	1.3657	6.75	53.2	2.25	17.7	11	86.6	1.09541	2
132407	30.0	119.11	0.457	0.042434	0.032019	995.57	1.3737	7.25	57.1	2.25	17.7	11	86.6	1.15425	2
142407	32.0	119.61	0.468	0.042602	0.033271	995.05	1.3704	7.75	61	2.25	17.7	11	86.6	1.19642	2
12507	18.5	108.13	0.027	0.045413	0.001734	998.53	1.2964	2.25	17.7	1.75	13.8	6	47.2	0.63508	1

TABLE S7 PRESSURE DROP, SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	SETTLING LENGTH,L INLET L/D	SETTLING LENGTH,L OUTLET L	SETTLING LENGTH,L OUTLET L/D	METRE FLOW PATRN L	METRE FLOW PATRN L/D	PR-GRAD KN/M3	FLOW PATTERN
22507	20.0	108.54	0.078	0.045269	0.003497	998.23	1.2946							--	16
32507	22.5	109.16	0.114	0.045165	0.005152	997.68	1.2910	7.25	57.1	1.75	13.8	10	78.7	0.67892	62
42507	24.0	110.06	0.152	0.045248	0.006856	997.32	1.2951	7.75	61	1.75	13.8	9	70.9	0.72177	2
52507	25.5	112.42	0.219	0.045269	0.010279	996.94	1.3161	7.75	61	2.25	17.7	9	70.9	0.81592	2
62507	27.0	114.02	0.280	0.045227	0.013386	996.54	1.3281	7.75	61	2.25	17.7	10	78.7	0.87564	2
72507	29.5	115.31	0.311	0.045351	0.015885	995.82	1.3321	4.75	37.4	1.75	13.8	10	78.7	0.94321	2
82507	31.0	117.04	0.354	0.045310	0.019878	995.36	1.3453	6.75	53.2	2.25	17.7	11	86.6	1.02382	2
112507	19.5	118.15	0.387	0.045248	0.024118	998.34	1.4117	5.25	41.3	1.75	13.8	11	86.6	1.12090	2
122507	22.0	119.11	0.399	0.045372	0.026874	997.80	1.4111	7.25	57.1	1.75	13.8	11	86.6	1.17975	2
132507	24.0	120.70	0.426	0.045248	0.031776	997.32	1.4203	6.25	49.2	2.25	17.7	11	86.6	1.25624	2
12807	19.0	102.73	0.025	0.047785	0.001724	998.44	1.3013	2.75	21.7	1.25	9.8	6	47.2	0.67784	1
22807	21.0	108.98	0.080	0.048078	0.003554	998.02	1.2955	5.25	41.3	1.25	9.8	10	78.7	--	16
32807	24.0	110.05	0.114	0.047746	0.005252	997.32	1.2949	5.75	45.3	1.25	9.8	10	78.2	0.74296	62

TABLE S8 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	SETTLING LENGTH,L INLET L/D	SETTLING LENGTH,L OUTLET L	SETTLING LENGTH,L OUTLET L/D	METRE FLOW PATRN L	METRE FLOW PATRN L/D	PR-GRAD KN/M3	FLOW PATTERN
42807	26.0	110.84	0.130	0.047922	0.006738	996.81	1.2954	5.75	45.3	1.25	9.8	10	78.7	0.77875	62
52807	28.0	113.04	0.197	0.047785	0.009812	996.25	1.3124	6.75	53.2	1.25	9.8	9	70.9	0.86534	2
62807	30.0	114.96	0.246	0.047706	0.013174	995.67	1.3258	4.75	37.4	1.25	9.8	11	86.6	0.95635	2
72807	32.0	116.59	0.299	0.047628	0.016703	995.05	1.3359	5.25	41.3	1.25	9.8	10	78.7	1.04735	2
22907	19.0	118.44	0.319	0.047981	0.020437	998.44	1.4175	8.25	65	1.25	9.8	11	86.6	1.18563	2
32907	21.5	119.67	0.349	0.047824	0.023812	997.91	1.4201	7.75	61	1.25	9.8	11	86.6	1.24643	2
42907	23.0	121.08	0.381	0.047628	0.028480	997.57	1.4295	7.25	57.1	1.25	9.8	11	86.6	1.32292	2
52907	26.0	122.76	0.413	0.047352	0.033722	996.81	1.4348	7.25	57.1	1.25	9.8	11	86.6	1.42884	2
23007	19.0	108.06	0.035	0.050566	0.001792	998.44	1.2933	4.25	33.5	1.25	9.8	6	47.2	0.77836	1
33007	20.5	109.72	0.071	0.050380	0.003573	998.13	1.3064	7.75	61	1.75	13.8	12	94.5	0.79111	16
43007	22.0	111.27	0.105	0.050454	0.005222	997.80	1.3181	8.25	65	1.75	13.8	11	86.6	0.84995	62
53007	24.0	112.14	0.122	0.050417	0.006881	997.32	1.3195	7.75	61	1.75	13.8	11	86.6	0.87172	62
63007	25.5	114.39	0.190	0.050361	0.009739	996.94	1.3392	4.25	33.5	1.75	13.8	10	78.7	0.94625	2

TABLE S9 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L				METRE		PR-GRAD KN/M3	FLOW PATTERN
								INLET		OUTLET		FLOW PATRN			
								L	L/D	L	L/D	L	L/D		
73007	28.0	116.95	0.244	0.050287	0.013681	996.26	1.3577	3.25	25.6	2.25	17.7	10	78.7	1.05716	2
83007	30.0	118.68	0.281	0.050268	0.016650	995.67	1.3688	3.25	25.6	2.25	17.7	11	86.6	1.13562	2
13107	19.5	119.25	0.301	0.050268	0.019378	998.34	1.4248	3.25	25.6	1.25	9.8	11	86.6	1.20720	2
23107	22.0	120.35	0.324	0.050361	0.021888	997.80	1.4257	6.75	53.2	1.25	9.8	10	78.7	1.27389	2
33107	24.5	122.28	0.359	0.050547	0.026714	997.20	1.4364	6.75	53.2	1.25	9.8	11	86.6	1.38372	2
43107	26.5	123.63	0.375	0.050473	0.029514	996.67	1.4425	8.25	65	1.25	9.8	11	86.6	1.44256	2
63107	18.5	108.76	0.024	0.052830	0.001781	998.53	1.3039	4.25	33.5	1.25	9.8	7	55.1	0.80758	1
73107	22.5	110.42	0.075	0.052866	0.003607	997.68	1.3058	6.25	49.2	1.25	9.8	12	94.5	0.84485	16
83107	24.0	111.87	0.105	0.052866	0.005041	997.32	1.3163	6.25	49.2	1.25	9.8	12	94.5	0.87329	62
93107	25.5	112.75	0.126	0.052759	0.006720	996.94	1.3200	6.75	53.2	1.25	9.8	12	94.5	0.90888	62
103107	27.5	115.14	0.179	0.052741	0.009716	996.40	1.3390	7.75	61	1.75	13.8	8	63	1.00224	2
113107	29.0	117.40	0.223	0.052581	0.012986	995.97	1.3585	5.25	41.3	1.75	13.8	8	63	1.10914	2
123107	31.0	120.06	0.265	0.052688	0.016800	995.36	1.3801	4.25	33.5	1.25	9.8	10	78.7	1.21211	2

TABLE S10 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	SETTLING LENGTH,L INLET L/D	SETTLING LENGTH,L OUTLET L	SETTLING LENGTH,L OUTLET L/D	METRE FLOW PATRN L	METRE FLOW PATRN L/D	PR-GRAD KN/M3	FLOW PATTERN
10108	19.0	121.19	0.287	0.052989	0.019324	998.44	1.4505	4.75	37.4	1.75	13.8	11	86.6	1.32683	2
20108	22.5	123.33	0.333	0.052670	0.025034	997.68	1.4586	5.75	45.3	1.25	9.8	11	86.6	1.42099	2
30108	26.0	125.00	0.372	0.052617	0.028970	996.81	1.4610	8.75	68.9	1.75	13.8	11	86.6	1.54946	2
40108	29.0	127.35	0.398	0.052617	0.033976	995.97	1.4736	8.25	65	1.75	13.8	10	78.7	1.66223	2
60108	19.0	111.11	0.039	0.054933	0.001743	998.44	1.3298	2.75	21.7	1.25	9.8	7	55.1	0.87633	1
70108	21.0	111.49	0.083	0.054933	0.003377	998.02	1.3252							--	16
80108	23.0	112.59	0.118	0.054933	0.005340	997.57	1.3293	7.25	57.1	1.25	9.8	12	94.5	0.96665	62
90108	24.0	113.43	0.148	0.054848	0.006954	997.32	1.3346	7.75	61	1.25	9.8	12	94.5	0.98753	62
100108	26.0	115.95	0.193	0.054933	0.009926	996.81	1.3552	7.25	57.1	1.25	9.8	9	70.9	1.08952	2
110108	28.5	118.33	0.238	0.054899	0.012925	996.11	1.3715	4.25	33.5	2.25	17.7	9	70.9	1.17385	2
120108	30.0	120.56	0.273	0.054848	0.016199	995.67	1.3904	4.25	33.5	1.25	9.8	10	78.7	1.27977	2
10408	20.0	122.63	0.266	0.055070	0.019311	998.23	1.4626	5.25	41.3	1.75	13.8	11	86.6	1.40530	2
20408	24.0	124.89	0.315	0.055053	0.024080	997.32	1.4695	5.25	41.3	2.25	17.7	12	94.5	1.51317	2

TABLE S11 PRESSURE DROP, SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L				METRE FLOW PATRN		PR-GRAD KN/M3	FLOW PATTERN
								INLET		OUTLET					
								L	L/D	L	L/D	L	L/D		
30408	27.0	128.70	0.369	0.054968	0.032312	996.54	1.4991	3.25	25.6	3.25	25.6	13	102.4	1.62595	2
60408	19.5	111.80	0.025	0.059877	0.001663	998.34	1.3358	3.25	25.6	1.25	9.8	8	63	1.01793	1
70408	21.5	112.38	0.067	0.059595	0.003503	997.91	1.3335							--	16
80408	23.5	114.39	0.105	0.059232	0.003148	997.45	1.3482	8.25	65	1.25	9.8	12	94.5	1.13071	62
90408	26.0	115.80	0.123	0.059705	0.006973	996.81	1.3534	7.25	57.1	1.75	13.8	11	86.6	1.21407	62
100408	28.0	117.63	0.163	0.059548	0.009065	996.26	1.3657	7.25	57.1	1.75	13.8	10	78.7	1.17092	2
110408	30.0	120.53	0.207	0.059090	0.012498	995.67	1.3901	5.25	41.3	2.25	17.7	10	78.7	1.30331	2
10508	21.0	123.90	0.260	0.058947	0.017434	998.02	1.4728	4.75	37.4	1.75	13.8	8	63	1.51121	2
20508	26.0	128.56	0.314	0.058915	0.024340	996.81	1.5026	5.25	41.3	2.25	17.7	11	86.6	1.67499	2
30508	29.0	132.82	0.368	0.059038	0.032252	995.97	1.5369	8.5	66.9	2.25	17.7	11	86.6	1.95447	2
70508	20.0	102.48	0.072	0.014549	0.001905	998.23	1.2224	7.75	61	1.25	9.8	4	31.5	0.08579	5
80508	22.0	102.93	0.205	0.014549	0.004294	997.80	1.2194	4.25	33.5	3.25	25.6	6	47.2	0.08954	6
90508	24.0	103.62	0.361	0.014549	0.009000	997.32	1.2192	5.75	45.3	2.25	25.6	7	55.1	0.11356	62

TABLE S12 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET		OUTLET		METRE FLOW PATRN		PR-GRAD KN/M3	FLOW PATTERN
								L	L/D	L	L/D	L	L/D		
100508	26.0	103.96	0.467	0.014549	0.013754	996.81	1.2151	3.25	25.6	3.25	25.6	8	63	0.14857	2
110508	28.0	104.97	0.551	0.014465	0.021384	996.26	1.2187	4.25	33.5	3.25	25.6	12	94.5	0.16593	2
120508	29.0	105.87	0.614	0.014626	0.030314	995.97	1.2250	3.25	25.6	2.75	21.7	11	86.6	0.20172	2
130508	30.5	107.08	0.680	0.014626	0.043694	995.52	1.2329	8.25	65	2.75	21.7	14	110.2	0.24703	2
11208	25.0	101.33	0.401	0.003543	0.002034	997.07	1.1882					4	31.5	0.03553	3
21208	26.5	101.33	0.407	0.003543	0.004315	996.67	1.1823					4	31.5	0.03596	3
31208	28.0	101.33	0.411	0.003543	0.007292	996.26	1.1764					5	39.4	0.03538	3
41208	30.0	101.33	0.413	0.003210	0.009751	995.67	1.1686					6	47.2	0.03426	3
51208	31.0	101.33	0.467	0.002999	0.014479	995.36	1.1647					6	47.2	0.02073	4
61208	22.0	101.33	0.432	0.003239	0.011391	997.80	1.2003					5	39.4	0.02538	3
71208	24.5	101.33	0.451	0.003210	0.017138	997.20	1.1902							0.02073	4
81208	26.5	101.33	--	0.003210	0.021566	996.67	1.1823							--	24
91208	27.5	101.33	--	0.003210	0.026406	996.40	1.1783							--	24

TABLE S13 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	SETTLING LENGTH,L INLET L/D	SETTLING LENGTH,L OUTLET L	SETTLING LENGTH,L OUTLET L/D	METRE FLOW PATRN L	METRE FLOW PATRN L/D	PR-GRAD KN/M3	FLOW PATTERN
101208	28.5	101.33	--	0.003210	0.030373	996.11	1.1744							--	2
111208	29.0	101.33	--	0.003030	0.034995	995.97	1.1725							--	2
121208	30.0	101.33	--	0.002999	0.038997	995.67	1.1686							--	2
131208	31.5	101.33	--	0.002903	0.046502	995.20	1.1628							--	2
11308	21.0	101.33	0.211	0.005559	0.001850	998.02	1.2044					10	78.7	0.02493	3
21308	23.5	101.33	--	0.005559	0.002374	997.45	1.1943					9	70.9	--	36
31308	24.5	101.33	0.220	0.005559	0.001938	997.20	1.1902					12	94.5	0.03551	3
41308	26.0	101.33	0.290	0.005559	0.002780	996.81	1.1843							0.03775	36
51308	28.0	101.33	--	0.005559	0.005007	996.26	1.1764							0.03903	2
61308	29.0	101.33	--	0.005559	0.008058	995.97	1.1725							0.03946	2
71308	30.0	101.33	--	0.005509	0.011802	995.67	1.1686							0.03818	2
81308	31.0	101.33	--	0.005475	0.022778	995.36	1.1647							0.04915	2
101308	21.0	101.67	--	0.005388	0.033259	998.02	1.2085							0.04569	2

TABLE S14 PRESSURE DROP, SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	L/D	OUTLET L	L/D	METRE FLOW PATRN L	L/D	PR-GRAD KN/M3	FLOW PATTERN
111308	22.5	101.72	--	0.005388	0.045955	997.68	1.2029							--	2
121308	24.0	101.74	0.126	0.007669	0.002011	997.32	1.1971							0.02720	6
131308	25.5	101.81	0.208	0.007645	0.003337	996.94	1.1919							0.03532	6
141308	27.0	101.75	0.372	0.007669	0.006453	996.54	1.1852							0.04231	26
151308	30.5	101.87	0.507	0.007657	0.011739	995.52	1.1730							0.05156	2
161308	29.0	102.29	0.607	0.007657	0.016596	995.97	1.1836							0.05370	2
191308	22.0	102.80	0.650	0.007620	0.023302	997.80	1.2178							0.07572	2
201308	23.5	102.87	0.702	0.007559	0.027851	997.45	1.2125							0.07784	2
211308	25.0	103.20	0.709	0.007521	0.034154	997.07	1.2102							0.07699	2
221308	27.0	103.55	0.736	0.007620	0.041049	996.54	1.2062							0.07277	2
231308	28.5	103.60	0.728	0.007596	0.045565	996.11	1.2008							0.06600	2
21408	22.0	102.01	0.105	0.009774	0.002021	997.80	1.2085							0.04583	6
31408	23.5	101.93	0.249	0.009917	0.004595	997.45	1.2014							0.05299	6

TABLE S15 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	INLET L/D	OUTLET L	OUTLET L/D	METRE FLOW PATRN L	METRE FLOW PATRN L/D	PR-GRAD KN/M3	FLOW PATTERN
41408	25.0	102.07	0.388	0.009898	0.007999	997.07	1.1970					7	55.1	0.06282	62
51408	26.5	102.09	0.502	0.009828	0.011714	996.67	1.1912					12	94.5	0.06982	62
61408	28.5	102.39	0.614	0.009841	0.017606	996.11	1.1858					12	94.5	0.07067	2
71408	29.5	102.98	0.654	0.009850	0.023825	995.82	1.1897					14	110.2	0.07209	2
91408	22.0	103.33	0.674	0.009926	0.030316	997.80	1.2240					12	94.5	0.03661	2
101408	23.0	103.72	0.695	0.009898	0.035228	997.57	1.2245					12	94.5	0.05342	2
111408	24.5	103.88	0.666	0.009926	0.042199	997.20	1.2203					14	110.2	0.08628	2
121408	27.0	104.09	0.697	0.009945	0.046427	996.54	1.2125					15	118.1	0.07351	2
131408	28.5	102.01	0.076	0.011892	0.002021	996.11	1.1824					2	15.8	0.05256	6
141408	29.5	102.09	0.257	0.011853	0.004970	995.82	1.1794					4	31.5	0.06610	6
151408	31.5	101.88	0.368	0.011853	0.008830	995.20	1.1692					6	47.2	0.07862	62
21508	22.0	102.38	0.444	0.011971	0.011680	997.80	1.2129					10	78.7	0.09423	2
31508	23.0	102.80	0.570	0.011971	0.018108	997.57	1.2136					10	78.7	0.07266	2

TABLE S16 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN* NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L				METRE FLOW PATRN		PR-GRAD KN/M3	FLOW PATTERN
								INLET		OUTLET					
								L	L/D	L	L/D	L	L/D		
41508	25.0	103.20	0.613	0.011971	0.022891	997.07	1.2192					10	78.7	0.06869	2
51508	27.0	103.63	0.664	0.012126	0.028410	996.54	1.2071					12	94.5	0.07180	2
61508	28.5	103.89	0.672	0.012111	0.034366	996.11	1.2042					14	110.2	0.07463	2
71508	29.0	104.60	0.712	0.012087	0.041884	995.97	1.2104					14	110.2	0.07748	2
81508	31.0	104.87	0.727	0.011971	0.045690	995.36	1.2054					14	110.2	0.07976	2
21808	22.0	101.99	0.160	0.013755	0.001899	997.80	1.2082						55.1	0.07011	6
31808	23.5	102.19	0.255	0.013755	0.004825	997.45	1.2044					8	63	0.08004	6
41808	25.0	102.26	0.335	0.013686	0.008389	997.07	1.1992					10	78.7	0.09395	2
51808	26.0	102.66	0.433	0.013755	0.011649	996.81	1.1998					10	78.7	0.10356	2
61808	27.0	103.41	0.556	0.013686	0.018275	996.54	1.2046					14	110.2	0.12749	2
71808	28.5	104.07	0.599	0.013686	0.024325	996.11	1.2062					14	110.2	0.13621	2
81808	30.0	104.46	0.651	0.013755	0.029462	995.67	1.2068					14	110.2	0.14298	2
21908	22.0	104.55	0.667	0.013686	0.034274	997.80	1.2366					14	110.2	0.11866	2

TABLE S17 PRESSURE DROP, SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	INLET L/D	OUTLET L	OUTLET L/D	METRE FLOW PATRN L	METRE FLOW PATRN L/D	PR-GRAD KN/M3	FLOW PATTERN
31908	25.0	105.35	0.698	0.013618	0.042353	997.07	1.2354					14	110.2	0.17348	2
41908	26.5	105.90	0.726	0.013686	0.047177	996.67	1.2357							0.16750	2
51908	29.0	102.73	0.086	0.013843	0.001946	995.97	1.1887					10	78.7	0.08187	6
61908	31.0	103.09	0.251	0.015724	0.005996	995.36	1.1850					10	78.7	0.10356	6
91908	22.0	103.06	0.433	0.015784	0.012554	997.80	1.2209					10	78.7	0.13161	2
101908	24.0	103.89	0.532	0.015724	0.017057	997.32	1.2225					10	78.7	0.15524	2
111908	25.0	104.38	0.566	0.015724	0.021947	997.07	1.2241					12	94.5	0.16917	2
121908	27.0	105.00	0.628	0.015724	0.027806	996.54	1.2231					12	94.5	0.17221	2
131908	28.0	105.32	0.659	0.015724	0.033708	996.26	1.2227					14	110.2	0.17554	2
141908	29.0	105.86	0.666	0.015724	0.037794	995.97	1.2249					14	110.2	0.18152	2
151908	30.0	106.41	0.697	0.015784	0.043875	995.67	1.2273					14	110.2	0.19084	2
12008	21.5	102.46	0.093	0.017204	0.002073	997.91	1.2159					8	63	0.09777	6
22008	25.0	102.66	0.226	0.017312	0.005295	997.07	1.2039					10	78.7	0.11121	6

TABLE S18 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	L/D	OUTLET L	L/D	METRE FLOW PATRN L	L/D	PR-GRAD KN/M3	FLOW PATTERN
32008	26.0	102.93	0.339	0.017149	0.008740	996.81	1.2031					10	78.7	0.12984	2
42008	27.5	103.35	0.430	0.017094	0.012366	996.40	1.2018					10	78.7	0.14004	2
52008	28.5	104.11	0.517	0.017094	0.017282	996.11	1.2067					13	102.4	0.17093	2
62008	30.0	104.63	0.585	0.017149	0.022014	995.67	1.2067					12	94.5	0.18613	2
72008	31.0	105.38	0.627	0.017094	0.028493	995.36	1.2113					12	94.5	0.19456	2
112008	23.0	105.70	0.631	0.017204	0.034328	997.57	1.2479					14	110.2	0.20064	2
122008	25.0	106.51	0.643	0.017094	0.040434	997.07	1.2491					14	110.2	0.22134	2
132008	27.0	106.71	0.675	0.017039	0.043861	996.54	1.2430					14	110.2	0.23203	2
12608	21.5	101.33	--	0.002737	0.048734	997.91	1.2024							--	2
22608	23.0	101.99	0.635	0.002448	0.070383	997.57	1.2042					4	31.5	0.01696	4
32608	24.5	102.25	0.699	0.002703	0.089305	997.20	1.2012					4	31.5	0.02379	4
42608	25.0	102.66	0.745	0.002967	0.119675	997.07	1.2039					4	31.5	0.03233	4
52608	27.0	103.19	0.776	0.003060	0.147767	996.54	1.2020					6	47.2	0.03988	4

TABLE S19 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	INLET L/D	OUTLET L	OUTLET L/D	METRE FLOW PATRN L	METRE FLOW PATRN L/D	PR-GRAD KN/M3	FLOW PATTERN
72608	21.5	104.38	0.853	0.003380	0.178388	997.91	1.2387					10	78.7	0.10621	5
82608	23.5	105.01	0.881	0.003352	0.207033	997.45	1.2377					10	78.7	0.10915	5
92608	24.0	101.33	0.880	0.003296	0.235250	997.32	1.1922							--	5
12708	20.5	105.81	0.890	0.003210	0.243086	998.13	1.2599					8	63	0.12307	5
22708	21.5	105.90	0.887	0.003210	0.259397	997.91	1.2567					8	63	0.14465	5
42708	21.5	106.80	0.894	0.002903	0.284470	997.91	1.2673					8	63	0.14975	5
52708	23.0	105.77	0.884	0.003060	0.244240	997.57	1.2487					8	63	0.13406	5
62708	24.0	104.00	0.875	0.002999	0.183986	997.32	1.2237					8	63	0.08591	52
12908	22.0	102.77	0.807	0.004539	0.047762	997.80	1.2174					14	110.2	0.10022	2
22908	25.5	103.17	0.828	0.004580	0.079775	996.94	1.2078					14	110.2	0.09512	2
32908	27.5	103.81	0.862	0.004641	0.100859	996.40	1.2072					14	110.2	0.07992	2
42908	28.5	104.35	0.836	0.004498	0.120374	996.11	1.2094					12	94.5	0.10572	25
52908	30.0	105.05	0.868	0.004285	0.143990	995.67	1.2116					12	94.5	0.16289	25

TABLE S20 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	L/D	OUTLET L	L/D	METRE FLOW PATRN L	L/D	PR-GRAD KN/M3	FLOW PATTERN
62908	30.5	105.74	0.859	0.004263	0.176974	995.52	1.2175							--	25
72908	30.5	106.51	0.858	0.004641	0.202923	995.52	1.2264					14	110-2	0.17476	52
92908	23.5	105.94	0.868	0.004539	0.176220	997.45	1.2487					13	102-4	0.14641	52
102908	24.5	107.50	0.866	0.004897	0.222358	997.20	1.2628					13	102-4	0.19456	5
112908	24.5	107.98	0.859	0.004800	0.244262	997.20	1.2685					12	94-5	0.19711	5
122908	25.0	108.83	0.874	0.004741	0.275652	997.07	1.2762					8	63	0.16573	5
10109	20.0	103.33	0.730	0.006898	0.047775	998.23	1.2324					14	110-2	0.07065	2
20109	22.0	104.36	0.825	0.005761	0.083753	997.80	1.2362					14	110-2	0.09433	2
30109	24.0	104.91	0.850	0.005705	0.105269	997.32	1.2345					14	110-2	0.12141	2
50109	20.5	106.56	0.841	0.006952	0.142917	998.13	1.2688					14	110-2	0.22036	2
60109	22.0	107.77	0.862	0.006843	0.175254	997.80	1.2767					14	110-2	0.22761	2
70109	24.0	103.50	0.851	0.006843	0.199007	997.32	1.2767					12	94-5	0.23644	2
80109	25.0	109.91	0.861	0.006843	0.231226	997.07	1.2889					13	102.4	0.26145	25

TABLE S21 PRESSURE DROP, SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	L/D	OUTLET L	L/D	METRE FLOW PATRN L	L/D	PR-GRAD KN/M3	FLOW PATTERN
90109	26.0	110.76	0.864	0.006774	0.255792	996.81	1.2945					12	94.5	0.24997	52
100109	26.5	111.42	0.864	0.006705	0.278555	996.57	1.3000					12	94.5	0.22840	5
10209	21.0	104.32	0.751	0.009161	0.048612	998.02	1.2400	9.75	76.8	1.75	13.8	13	102.4	0.14710	2
20209	25.0	105.38	0.737	0.009109	0.077867	997.07	1.2357	10.3	80.7	1.25	9.8	14	110.2	0.17162	2
30209	27.5	106.33	0.845	0.008975	0.110214	996.40	1.2423	6.25	49.2	5.25	41.3	14	110.2	0.28930	2
40209	29.0	108.32	0.847	0.009181	0.148206	995.97	1.2534	6.25	49.2	2.25	17.7	14	110.2	0.32107	25
10309	21.5	110.04	0.846	0.009079	0.171563	997.91	1.3058	5.25	41.3	4.25	33.5	14	110.2	0.33735	2
20309	23.0	111.49	0.852	0.008870	0.207266	997.57	1.3162	2.75	21.7	7.25	57.1	14	110.2	0.34902	25
40309	21.0	112.97	0.853	0.008943	0.239274	998.02	1.3428	3.25	25.6	6.25	49.2	14	110.2	0.26017	52
50309	22.5	114.10	0.867	0.008922	0.277891	997.68	1.3494	6.25	49.2	2.25	17.7	12	94.5	0.26537	5
10409	20.5	105.90	0.723	0.012318	0.055662	998.13	1.2610	3.75	29.5	1.25	9.8	14	110.2	0.22124	2
20409	24.5	106.78	0.759	0.012318	0.076389	997.20	1.2543	3.25	25.6	1.25	9.8	14	110.2	0.27822	2
30409	26.5	109.22	0.797	0.012431	0.108844	996.57	1.2744	3.25	25.6	1.75	13.8	14	110.2	0.39619	2

TABLE S22 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	L/D	OUTLET L	L/D	METRE FLOW PATRN L	L/D	PR-GRAD KN/M3	FLOW PATTERN
40409	28.5	111.80	0.811	0.012431	0.149046	996.11	1.2958	2.25	17.7	4.25	33.5	14	110.2	0.43669	2
50409	29.0	113.75	0.819	0.012394	0.183451	995.97	1.3163							--	2
60409	30.0	115.32	0.821	0.012581	0.211403	995.67	1.3300							--	25
10509	20.5	116.29	0.815	0.012394	0.221935	998.13	1.3847	2.75	21.7	5.75	45.3	14	110.2	0.44228	25
20509	22.0	117.95	0.336	0.012469	0.250144	997.80	1.3973	4.25	33.5	5.25	41.3	14	110.2	0.44571	52
30509	23.0	119.94	0.846	0.012394	0.278893	997.57	1.4160	4.25	33.5	4.75	37.4	14	110.2	0.46788	52
50509	22.5	106.57	0.720	0.015055	0.052699	997.68	1.2604	5.75	45.3	2.75	21.7	14	110.2	0.29420	2
60509	23.0	108.50	0.756	0.015271	0.078716	997.07	1.2724	5.75	45.3	1.25	9.8	14	110.2	0.39766	2
70509	27.5	111.37	0.773	0.015179	0.108538	996.40	1.2951	6.25	49.2	5.75	45.3	14	110.2	0.48112	2
80309	29.0	114.06	0.792	0.015179	0.144181	995.97	1.3199	6.25	49.2	6	47.3	14	110.2	--	2
10809	21.0	116.72	0.784	0.015210	0.176162	998.02	1.3875	6.25	49.2	4.25	33.5	14	110.2	0.63783	2
20809	23.0	118.88	0.799	0.015179	0.204781	997.57	1.4035	2.75	21.7	4.25	33.5	15	118.1	0.62410	25
30809	24.5	120.13	0.800	0.015271	0.229919	997.20	1.4112	4.25	33.5	3.75	29.5	14	110.2	0.63214	25

TABLE S23 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	L/D	OUTLET L	L/D	METRE FLOW PATRN L	L/D	PR-GRAD KN/M3	FLOW PATTERN
50809	21.0	107.10	0.673	0.017176	0.049293	998.02	1.2731	2.25	17.7	5.25	41.3	12	94.5	0.36295	2
60809	23.5	109.75	0.706	0.017258	0.078160	997.45	1.2935	6.25	49.2	1.25	9.8	14	110.2	0.45376	2
70809	25.5	112.63	0.737	0.017176	0.108654	996.94	1.3186	5.25	41.3	3.75	29.5	14	110.2	0.56133	2
80809	28.0	115.33	0.766	0.017204	0.137687	996.26	1.3390	5.25	41.3	4.75	37.4	14	110.2	0.60213	2
90809	30.0	118.99	0.787	0.017149	0.178059	995.67	1.3723	8.25	65	4.75	33.5	14	110.2	0.76806	2
10909	21.5	121.35	0.791	0.017258	0.206506	997.91	1.4400	6.25	49.2	6.25	49.2	14	110.2	--	2
20909	22.5	123.13	0.811	0.017258	0.223065	997.68	1.4561	6.25	49.2	6.25	49.2	15	118.1	0.86779	25
30909	23.5	125.61	0.825	0.017204	0.258270	997.45	1.4805	5.25	41.3	4.25	33.5	15	118.1	0.89702	52
40909	24.0	122.86	0.850	0.015241	0.264508	997.32	1.4457	4.25	33.5	5.25	41.3	15	118.1	0.67146	52
11109	20.5	108.27	0.651	0.018525	0.053023	998.13	1.2892	6.25	49.2	1.25	9.8	14	110.2	0.39756	2
21109	23.5	112.02	0.664	0.018464	0.082895	997.45	1.3204	7.25	57.1	4.25	33.5	14	110.2	--	2
31109	25.0	115.02	0.687	0.018905	0.118858	997.07	1.3488	6.25	49.2	4.25	33.5	14	110.2	0.50965	2
41109	27.0	118.32	0.720	0.019029	0.152612	996.54	1.3783	6.25	49.2	5.75	45.3	14	110.2	0.57403	2

TABLE S24 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C.	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L		OUTLET L		METRE FLOW PATRN L		PR-GRAD KN/M3	FLOW PATTERN
									L/D		L/D		L/D		
71109	19.5	120.28	0.738	0.018716	0.180618	998.34	1.4371	6.25	49.2	4.75	37.4	14	110.2	0.65381	25
81109	21.0	123.80	0.764	0.018905	0.212296	998.02	1.4716	5.25	41.3	4.75	37.4	14	110.2	0.79317	25
91109	22.5	126.10	0.789	0.019029	0.235871	997.68	1.4913	4.75	37.4	4.75	37.4	14	110.2	0.91114	52
101139	23.0	125.87	0.814	0.019087	0.259797	997.57	1.5215	5.25	41.3	4.75	37.4	14	110.2	1.01793	52
11209	19.5	110.93	0.613	0.024194	0.051213	998.34	1.3253	6.25	49.2	2.75	21.7	15	118.1	0.61704	2
21209	21.5	118.24	0.666	0.024245	0.105313	997.91	1.4031	6.25	49.2	4.25	33.5	14	110.2	0.79111	2
31209	25.0	124.24	0.717	0.024578	0.151379	997.07	1.4570	7.25	57.1	4.25	33.5	14	110.2	1.15719	2
41209	26.5	126.61	0.751	0.024291	0.174208	996.67	1.4773	7.25	57.1	4.25	33.5	14	110.2	--	.2
51209	27.0	130.21	0.787	0.024097	0.200251	996.54	1.5167	5.25	41.3	4.25	33.5	14	110.2	1.36411	25
81209	20.0	132.10	0.765	0.024245	0.209439	998.23	1.5756	5.25	41.3	4.75	37.4	15	118.1	1.52592	52
91209	22.0	136.58	0.798	0.024483	0.243996	997.80	1.6180	6.75	53.2	4.75	37.4	15	118.4	1.80149	52
11509	18.5	114.56	0.577	0.028807	0.054958	998.53	1.3735	5.75	45.3	4.25	33.5	13	102.2	0.76276	2
21509	21.5	120.68	0.632	0.029091	0.096038	997.91	1.4321	6.75	53.2	4.25	33.5	14	110.2	1.16209	2

TABLE S25 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L				METRE FLOW PATRN		PR-GRAD KN/M3	FLOW PATTERN
								INLET		OUTLET					
								L	L/D	L	L/D	L	L/D		
31509	24.0	128.15	0.694	0.029011	0.137628	997.32	1.5078	7.25	57.1	4.25	33.5	14	110.2	1.68577	2
41509	26.5	133.49	0.743	0.028686	0.170571	996.67	1.5576	5.25	41.3	4.25	33.5	15	118	1.76324	25
61509	19.0	136.44	0.735	0.029049	0.183765	998.44	1.6330	6.75	53.2	4.75	37.4	15	118	2.05156	25
71509	22.0	139.40	0.752	0.029091	0.207402	997.80	1.6513	6.25	49.2	5.25	41.3	15	118	2.18885	25
81509	22.5	143.86	0.767	0.029133	0.233863	997.68	1.7013	3.25	25.6	5.25	41.3	15	118	2.25162	25
11609	19.0	142.78	0.753	0.032921	0.179432	998.44	1.7088	5.25	41.3	2.75	21.7	15	118	0.98067	2
21609	21.5	145.85	0.782	0.032526	0.202532	997.91	1.7307	6.25	49.2	3.75	29.5	15	118	1.45727	2
31609	23.0	150.92	0.818	0.032598	0.230090	997.57	1.7818	6.25	49.2	5.25	41.3	15	118	1.77795	2
51609	18.5	116.42	0.541	0.032742	0.033244	998.53	1.3957	7.25	57.1	3.25	25.6	13	102	2.39578	2
61609	22.0	124.23	0.561	0.032451	0.097024	997.80	1.4717	5.75	45.3	5.25	41.3	14	110	2.46148	2
71609	26.0	131.60	0.688	0.032451	0.131266	996.81	1.5381	5.75	45.3	5.25	41.3	15	118	2.58210	2
81609	27.0	136.09	0.751	0.032345	0.170894	996.54	1.5253	9.25	72.8	4.25	33.5	15	118	2.84106	2
11709	18.5	120.33	0.499	0.039480	0.050398	998.53	1.4426	5.75	45.3	2.25	17.7	12	94.5	1.24153	2

TABLE S26 PRESSURE DROP, SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	SETTLING LENGTH,L INLET L/D	SETTLING LENGTH,L OUTLET L	SETTLING LENGTH,L OUTLET L/D	METRE FLOW PATRN L	METRE FLOW PATRN L/D	PR-GRAD KN/M3	FLOW PATTERN
21709	21.5	128.69	0.593	0.039330	0.081329	997.91	1.5271	5.25	41.34	6.25	49.2	12	94.5	1.55240	2
31709	24.5	145.85	0.652	0.039299	0.117507	997.20	1.7132	6.25	49.2	—	—	14	110	2.38793	2
41709	27.0	146.44	0.713	0.039359	0.151851	996.56	1.7058	4.75	37.4	5.25	41.3	15	118	--	2
11809	19.5	153.94	0.719	0.039480	0.171673	998.36	1.8393	3.25	25.6	5.25	41.3	15	118	3.09793	2
21809	20.0	161.63	0.752	0.039299	0.203970	998.23	1.9278	5.75	45.3	5.25	41.3	15	118	3.70301	2
41809	18.0	124.09	0.459	0.045413	0.045484	998.63	1.4902	5.25	41.3	4.25	33.5	12	94.5	1.63854	2
51809	21.5	135.73	0.572	0.043020	0.087299	997.91	1.6106	6.75	53.2	2.25	17.7	12	94.5	2.30359	2
61809	24.5	145.97	0.641	0.045061	0.119994	997.20	1.7146	5.25	41.3	4.25	33.5	14	110	2.95181	2
11909	17.5	159.18	0.696	0.045537	0.150894	998.72	1.9149	6.75	53.2	4.25	33.5	15	118	4.06585	2
21909	20.0	170.92	0.729	0.045681	0.186161	998.23	2.0386	6	47.2	4.25	33.5	15	118	4.65033	2
12209	18.0	127.94	0.441	0.050417	0.045050	998.63	1.5365	6.25	49.2	4.25	33.5	12	94.5	1.74363	2
22209	21.0	139.87	0.524	0.050640	0.079556	998.02	1.6626	5.25	41.3	4.25	33.5	12	94.5	2.45952	2
32209	24.5	153.05	0.624	0.049687	0.114627	997.20	1.7978	5.25	41.3	4.25	33.5	12	94.5	3.38919	2

TABLE S27 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP	P MEAN	VOID FRCTN	WATER FLOW RATE	AIR FLOW RATE	DENSITY WATER	DENSITY AIR	SETTLING LENGTH,L INLET		OUTLET		METRE FLOW PATRN		PR-GRAD	FLOW PATTERN
	C	KN/M2		M3/SEC	M3/SEC	KG/M3	KG/M3	L	L/D	L	L/D	L	L/D	KN/M3	
42209	27.0	165.52	0.687	0.049913	0.145952	996.56	1.9281	6	47.2	4.25	33.5	12	94.5	4.35617	2
12309	18.0	131.85	0.408	0.055053	0.045085	998.63	1.5835	6.25	49.2	2.25	17.7	12	94.5	1.99762	2
22309	21.0	146.03	0.519	0.055002	0.078281	998.02	1.7358	6.25	49.2	2.25	17.7	12	94.5	2.98222	2
32309	25.0	160.21	0.605	0.054882	0.113395	997.07	1.8787	7.25	57.1	4.75	37.4	12	94.5	3.84422	2
52309	19.5	136.47	0.428	0.058931	0.044951	998.34	1.6306	3.25	25.6	6.25	49.2	12	94.5	1.98684	2
62309	22.0	159.11	0.580	0.057792	0.077439	997.80	1.8849	5.25	41.3	4.25	33.5	12	94.5	3.27838	2
72309	25.0	161.41	0.658	0.055914	0.116469	997.07	1.8929	6.25	49.2	5.25	41.3	12	94.5	4.17961	2

TABLE S28 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	L/D	OUTLET L	L/D	METRE FLOW PATRN L	L/D	PR-GRAD KN/M3	FLOW PATTERN
90910	16.0	101.33	0.577	0.001499	0.001763	998.97	1.2253							--	3
100910	16.0	101.33	0.590	0.001499	0.001854	998.97	1.2253							--	3
110910	16.5	101.33	0.596	0.001499	0.002590	998.89	1.2232							--	3
120910	17.0	101.33	0.593	0.001499	0.003031	998.80	1.2211							--	3
130910	18.0	101.33	--	0.001499	0.005686	998.63	1.2169							--	3
140910	18.5	101.33	0.536	0.001499	0.009240	998.53	1.2148							--	3
150910	19.0	101.33	0.597	0.001499	0.012481	998.44	1.2127							--	34
160910	19.5	101.33	0.594	0.001499	0.017229	998.34	1.2106							--	34
170910	20.0	101.33	0.588	0.001499	0.021500	998.23	1.2085							--	4
180910	20.0	101.33	0.646	0.001499	0.026040	998.23	1.2085							--	4
190910	21.5	101.33	--	0.001499	0.031502	997.91	1.2024							--	42
200910	22.0	101.33	--	0.001499	0.036509	997.80	1.2003							--	42
210910	23.0	101.33	--	0.001499	0.039456	997.57	1.1963							--	42

TABLE S29 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	SETTLING LENGTH,L INLET L/D	OUTLET L	OUTLET L/D	METRE FLOW PATRN L	METRE FLOW PATRN L/D	PR-GRAD KN/M3	FLOW PATTERN
220910	24.0	101.33	--	0.001499	0.042397	997.32	1.1922							--	42
230910	16.0	101.33	0.516	0.002371	0.001763	998.97	1.2253							--	3
240910	16.0	101.33	0.520	0.002371	0.002616	998.97	1.2253							--	3
250910	16.5	101.33	0.527	0.002371	0.004192	998.89	1.2232							--	3
260910	17.0	101.33	0.525	0.002371	0.008373	998.80	1.2211							--	3
270910	17.5	101.33	0.526	0.002371	0.012496	998.72	1.2190							--	3
280910	18.0	101.33	0.534	0.002371	0.019390	998.63	1.2169							--	4
290910	19.5	101.33	--	0.002371	0.023629	998.34	1.2106							--	42
300910	20.0	101.33	--	0.002371	0.026311	998.23	1.2085							--	2
310910	21.0	101.33	--	0.002371	0.030144	998.02	1.2044							--	2
320910	22.0	101.33	--	0.002371	0.035537	997.80	1.2003							--	2
330910	22.0	101.33	--	0.002371	0.037821	997.80	1.2003							--	2
340910	23.0	101.33	--	0.002371	0.041494	997.57	1.1963							--	2

TABLE S30 PRESSURE DROP, SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	L/D	OUTLET L	L/D	METRE FLOW PATRN L	L/D	PR-GRAD KN/M3	FLOW PATTERN
350910	23.0	101.33	:--	0.002371	0.045428	997.57	1.1963							--	2
11010	15.0	101.33	0.291	0.004435	0.001757	999.13	1.2296							--	3
21010	15.0	101.33	:--	0.004435	0.001908	999.13	1.2296							--	34
31010	16.0	101.33	0.300	0.004435	0.002555	998.97	1.2253							--	4
41010	16.0	101.33	:--	0.004435	0.002958	998.97	1.2253							--	4
51010	16.0	101.33	:--	0.004435	0.004118	998.97	1.2253							--	62
61010	16.5	101.33	:--	0.004435	0.005297	998.89	1.2232							--	62
71010	17.0	101.33	:--	0.004435	0.007969	998.80	1.2211							--	2
81010	18.0	101.33	:--	0.004498	0.010056	998.63	1.2169							--	2
91010	18.5	101.33	:--	0.004498	0.012139	998.53	1.2148							--	2
101010	18.5	101.33	:--	0.004498	0.017705	998.53	1.2148							--	2
111010	19.0	101.33	:--	0.004498	0.021477	998.44	1.2127							--	2
121010	19.5	101.33	:--	0.004371	0.030156	998.36	1.2106							--	2

TABLE S31 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L METRE						PR-GRAD KN/M3	FLOW PATTERN
								INLET		OUTLET		FLOW PATRN			
								L	L/D	L	L/D	L	L/D		
131010	20.0	101.33	:--	0.004741	0.034456	993.23	1.2085							--	2
141010	20.0	101.33	:--	0.004741	0.041178	998.23	1.2085							--	2
151010	21.0	101.33	:--	0.007307	0.001794	998.02	1.2044							--	6
161010	21.0	101.33	:--	0.007307	0.001917	998.02	1.2044							--	6
171010	21.5	101.33	:--	0.007370	0.002572	997.91	1.2024							--	6
181010	22.0	101.33	:--	0.007370	0.003116	997.80	1.2003							--	6
191010	22.5	101.33	:--	0.007370	0.004042	997.68	1.1983							--	62
201010	23.0	101.33	:--	0.007370	0.005784	997.57	1.1963							--	62
211010	23.0	101.33	:--	0.007370	0.008135	997.57	1.1963							--	2
221010	23.0	101.33	:--	0.007370	0.009805	997.57	1.1963							--	2
231010	23.5	101.33	:--	0.007370	0.012754	997.45	1.1943							--	2
241010	23.5	101.33	:--	0.007370	0.017647	997.45	1.1943							--	2
251010	24.0	101.33	:--	0.007370	0.023987	997.32	1.1922							--	2

TABLE S32 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L		OUTLET L		METRE FLOW PATRN L		PR-GRAD KN/M3	FLOW PATTERN
									L/D		L/D		L/D		
261010	24.0	101.33	--	0.007370	0.029803	997.32	1.1922							--	2
271010	24.5	101.33	--	0.007370	0.036959	997.20	1.1902							--	2
281010	25.0	101.33	--	0.007370	0.043375	997.07	1.1882							--	2
291010	15.0	101.33	0.037	0.018651	0.001847	999.13	1.2296							--	6
301010	16.0	101.33	0.096	0.018716	0.002432	998.97	1.2253							--	6
311010	17.0	101.33	0.123	0.018781	0.003000	998.80	1.2211							--	6
321010	18.0	101.33	0.174	0.018781	0.004080	998.63	1.2169							--	62
331010	19.0	101.33	0.215	0.018781	0.005343	998.44	1.2127							--	62
341010	20.0	101.33	0.334	0.018781	0.007649	998.23	1.2085							--	2
351010	20.5	101.33	0.376	0.018781	0.010983	998.13	1.2065							--	2
361010	21.0	101.33	--	0.018651	0.016657	998.02	1.2044							--	2
371010	21.5	101.33	0.573	0.018525	0.027166	997.91	1.2024							--	2
381010	23.0	101.33	0.655	0.018337	0.042087	997.57	1.1963							--	2

TABLE S33 PRESSURE DROP, SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET		OUTLET		METRE FLOW PATRN		PR-GRAD KN/M3	FLOW PATTERN
								L	L/D	L	L/D	L	L/D		
391010	24.0	101.33	0.059	0.040420	0.001905	997.32	1.1922							--	16
401010	25.0	101.33	0.068	0.040276	0.002603	997.07	1.1882							--	16
411010	25.5	101.33	--	0.040362	0.003023	996.94	1.1862							--	16
421010	26.0	101.33	0.094	0.040420	0.004295	996.81	1.1843							--	16
431010	27.0	101.33	--	0.040362	0.005489	996.54	1.1803							--	62
441010	27.5	101.33	0.186	0.040508	0.008259	996.40	1.1783							--	2
451010	28.0	101.33	0.247	0.040566	0.012116	996.26	1.1764							--	2
461010	28.0	101.33	0.345	0.040566	0.019566	996.26	1.1764							--	2
471010	28.5	101.33	0.446	0.040566	0.032209	996.11	1.1744							--	2
481010	29.0	101.33	0.477	0.040129	0.039579	995.97	1.1725							--	2
491010	29.5	101.33	0.039	0.064323	0.001972	995.82	1.1705							--	1
501010	30.0	101.33	0.088	0.064141	0.003768	995.67	1.1686							--	1
511010	30.0	101.33	--	0.063217	0.007256	995.67	1.1686							--	16

TABLE S 34 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	L/D	OUTLET L	L/D	METRE FLOW PATRN L	L/D	PR-GRAD KN/M3	FLOW PATTERN
521010	30.5	101.33	0.177	0.061522	0.013721	995.52	1.1667							--	2
10810	18.5	101.33	0.762	0.001369	0.041579	998.53	1.2148							--	4
20810	20.0	101.33	0.773	0.001369	0.081117	998.23	1.2085							--	4
30810	21.0	101.33	0.846	0.001369	0.128161	998.02	1.2044							--	4
40810	22.5	101.33	0.896	0.001369	0.173336	997.68	1.1983							--	4
50810	23.0	101.33	0.934	0.001369	0.224156	997.57	1.1963							--	4
60810	24.0	101.33	0.957	0.001369	0.262003	997.32	1.1922							--	54
70810	24.0	101.33	0.966	0.001369	0.340654	997.32	1.1922							--	54
80810	17.0	101.33	--	0.002290	0.046059	998.80	1.2211							--	42
90810	18.0	101.33	0.701	0.002290	0.083357	998.63	1.2169							--	4
100810	20.0	101.33	0.790	0.002249	0.128656	998.23	1.2085							--	4
110810	21.0	101.33	0.839	0.002249	0.177691	998.02	1.2044							--	4
120810	22.0	101.33	0.892	0.002371	0.210579	997.80	1.2003							--	45

TABLE S35 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	SETTLING LENGTH,L INLET L/D	OUTLET L	OUTLET L/D	METRE FLOW PATRN L	METRE FLOW PATRN L/D	PR-GRAD KN/M3	FLOW PATTERN
130810	22.0	101.33	0.914	0.002290	0.264016	997.80	1.2003							--	5
140810	22.5	101.33	0.921	0.002371	0.331387	997.68	1.1983							--	5
150810	16.0	101.33	--	0.003773	0.050804	998.97	1.2253							--	2
160810	17.0	101.33	--	0.003871	0.094447	998.80	1.2211							--	2
170810	18.5	101.33	--	0.003371	0.113033	998.53	1.2148							--	2
180810	20.0	101.33	0.871	0.003871	0.170162	998.23	1.2085							--	2
190810	21.0	101.33	0.899	0.003871	0.243477	998.02	1.2044							--	52
200810	22.0	101.33	0.895	0.003822	0.289177	997.80	1.2003							--	5
210810	22.0	101.33	0.917	0.003871	0.334844	997.80	1.2003							--	5
10910	15.0	101.33	--	0.005887	0.049401	999.13	1.2296							--	2
20910	17.0	101.33	0.825	0.005807	0.087339	998.80	1.2211							--	2
30910	18.0	101.33	0.866	0.005807	0.135899	998.63	1.2169							--	2
40910	19.5	101.33	0.869	0.005887	0.199379	998.34	1.2106							--	25

TABLE S36 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET		OUTLET		METRE FLOW PATRN		PR-GRAD KN/M3	FLOW PATTERN
								L	L/D	L	L/D	L	L/D		
50910	20.0	101.33	0.880	0.005807	0.238182	998.23	1.2085							--	52
60910	21.0	101.33	0.880	0.005742	0.262807	998.02	1.2044							--	52
70910	21.5	101.33	0.880	0.005725	0.297365	997.91	1.2024							--	5
80910	22.0	101.33	0.897	0.005013	0.325436	997.80	1.2003							--	5

TABLE S 37 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	INLET L/D	OUTLET L	OUTLET L/D	METRE FLOW PATRN L	METRE FLOW PATRN L/D	PR-GRAD KN/M3	FLOW PATTERN
10801	13.0	102.97	0.131	0.018778	0.001876	999.40	1.2583	5.75	45.3	1.25	9.8			0.14588	6
20801	16.0	103.14	0.199	0.018653	0.003762	998.97	1.2472	3.75	29.5	1.25	9.8			0.15955	2
30801	17.0	103.29	0.237	0.018778	0.005627	998.80	1.2447	3.75	29.5	1.25	9.8			0.17055	2
40801	19.0	103.44	0.290	0.018778	0.007443	998.44	1.2380							--	2
50801	21.0	103.90	0.336	0.018778	0.010542	998.02	1.2351	5.25	41.3	1.25	9.8			0.20953	2
60801	23.0	105.19	0.532	0.018778	0.019282	997.57	1.2419	9.25	72.8	1.5	11.8			0.26478	2
70801	24.0	106.93	0.660	0.018653	0.035388	997.32	1.2582	10.75	84.6	1.25	9.8			0.40381	2
90801	11.0	104.14	0.105	0.024388	0.001886	999.63	1.2816	4.75	37.4	1.25	9.8			0.23207	62
100801	13.0	104.50	0.184	0.024291	0.003790	999.40	1.2770	5.75	45.3	1.25	9.8			0.26746	2
110801	14.0	105.08	0.269	0.024194	0.007597	999.27	1.2796	7.75	61	1.25	9.8			0.31143	2
120801	16.0	106.00	0.371	0.024436	0.012974	998.97	1.2819	4.25	33.5	1.25	9.8			0.36953	2
130801	18.0	107.25	0.469	0.024339	0.021483	998.63	1.2880	8.75	68.9	1.25	9.8			0.47269	2
140801	20.0	108.88	0.593	0.024243	0.033655	998.23	1.2986	10.75	84.9	1.25	9.8			0.55524	2

TABLE S38 PRESSURE DROP, SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L				METRE FLOW PATRN		PR-GRAD KN/M3	FLOW PATTERN
								INLET		OUTLET					
								L	L/D	L	L/D	L	L/D		
150801	22.5	111.72	0.622	0.024291	0.043070	997.68	1.3212							--	2
10901	10.0	105.00	0.089	0.029172	0.001927	999.72	1.2968	7.75	61	1.25	9.8			0.32689	62
20901	12.0	105.70	0.163	0.028848	0.003741	999.52	1.2962	7.75	61	1.25	9.8			0.36963	2
30901	15.0	106.29	0.234	0.029091	0.007297	999.13	1.2898	7.75	61	1.25	9.8			0.42224	2
40901	17.0	106.90	0.312	0.029252	0.010355	998.80	1.2882	9.75	76.8	1.25	9.8			0.47426	2
50901	19.0	108.16	0.420	0.029010	0.017835	998.44	1.2945	7.25	57.1	1.25	9.8			0.54628	2
60901	20.5	109.48	0.500	0.029091	0.025008	998.13	1.3036	9.25	72.8	1.75	13.8			0.68220	2
70901	22.5	111.27	0.568	0.028929	0.033666	997.68	1.3159	11.3	88.6	1.75	13.8			0.84852	2
80901	24.0	116.56	0.508	0.028766	0.042421	997.32	1.3715							--	2
100901	12.0	105.58	0.081	0.032525	0.001806	999.52	1.2947	7.75	61	1.25	9.8			0.39616	16
110901	14.0	106.54	0.155	0.032525	0.003960	999.27	1.2974	7.75	61	1.25	9.8			0.42695	26
120901	16.0	107.13	0.229	0.032344	0.007583	998.97	1.2955	9.75	76.8	1.25	9.8			0.50498	2
130901	19.0	108.00	0.295	0.032884	0.010739	998.44	1.2926	9.75	76.8	1.25	9.8			0.58423	2

TABLE S39 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L METRE INLET		OUTLET		FLOW PATRN		PR-GRAD KN/M3	FLOW PATTERN
								L	L/D	L	L/D	L	L/D		
140901	22.0	109.15	0.400	0.032849	0.017081	997.80	1.2931	5.25	41.3	1.25	9.8			0.64337	2
150901	24.5	111.07	0.477	0.032864	0.024967	997.20	1.3047	10.75	84.6	1.25	9.8			0.82512	2
160901	26.0	114.23	0.519	0.032956	0.033565	996.81	1.3351							--	2
170901	28.0	118.21	0.458	0.032705	0.040334	996.26	1.3724							--	2
11201	12.0	106.80	0.075	0.033940	0.001898	999.52	1.3096	5.75	45.3	1.25	9.8			0.54062	16
21201	14.0	107.71	0.119	0.039449	0.003708	999.27	1.3116	8.75	68.9	1.25	9.8			0.60774	62
31201	16.5	108.48	0.180	0.039390	0.007250	998.89	1.3096	7.25	57.1	1.25	9.8			0.64626	2
41201	19.0	109.39	0.245	0.039330	0.010175	998.46	1.3092	6.5	51.2	1.25	9.8			0.70407	2
51201	21.0	111.87	0.359	0.039449	0.017810	998.02	1.3297	6.5	51.2	1.25	9.8			0.85037	2
61201	23.0	115.05	0.439	0.039240	0.028608	997.57	1.3584	11.25	88.6	1.25	9.8			1.08125	2
71201	25.0	119.31	0.446	0.039449	0.038380	997.07	1.3992	11.75	92.5	1.25	9.8			1.51754	2
91201	11.0	108.35	0.066	0.045172	0.001787	999.63	1.3333	9.25	72.8	1.25	9.8			0.71589	16
101201	13.0	108.77	0.107	0.045198	0.003617	999.40	1.3291	9.50	74.8	1.25	9.8			0.75748	62

TABLE S40 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET		OUTLET		METRE FLOW PATRN		PR-GRAD KN/M3	FLOW PATTERN
								L	L/D	L	L/D	L	L/D		
111201	15.0	109.95	0.154	0.045042	0.007130	999.13	1.3342	9.25	72.8	1.25	9.8	—		0.81831	2
121201	17.0	111.75	0.218	0.045016	0.010451	998.80	1.3467	9.25	72.8	1.25	9.8			0.89311	2
131201	19.5	114.76	0.315	0.045432	0.016966	998.34	1.3711	10.25	80.7	1.25	9.8			1.12619	2
141201	21.5	117.72	0.374	0.045068	0.025719	997.91	1.3970	11.25	88.6	1.25	9.8			1.34842	2
151201	23.0	122.91	0.421	0.045483	0.037972	997.57	1.4511	11.75	92.5	1.25	9.8			1.74188	2
11601	11.0	109.17	0.073	0.050271	0.001800	999.63	1.3435	2.25	17.7	1.25	9.8			0.78454	16
21601	12.0	109.67	0.096	0.050271	0.003851	999.52	1.3449	5.25	41.3	1.25	9.8			0.85561	62
31601	14.0	111.06	0.144	0.050341	0.007328	999.27	1.3524	5.75	45.3	1.25	9.8			0.92837	2
41601	17.0	114.45	0.232	0.050036	0.011875	998.80	1.3792	7.25	57.1	1.25	9.8			1.04435	2
51601	19.0	117.36	0.290	0.050434	0.017507	998.44	1.4046	8.75	68.9	1.75	13.8			1.18906	2
61601	21.0	121.64	0.353	0.050387	0.029184	998.02	1.4459	8.75	68.9	1.75	13.8			1.38307	2
71601	23.0	125.90	0.410	0.050271	0.040077	997.57	1.4864	9.25	72.8	2.25	17.7			1.53496	2
91601	11.0	110.87	0.063	0.054962	0.001729	999.63	1.3643	7.75	61	1.25	9.8			0.97307	1

TABLE S41 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	INLET L/D	OUTLET L	OUTLET L/D	METRE FLOW PATRN L	METRE FLOW PATRN L/D	PR-GRAD KN/M3	FLOW PATTERN
101601	13.0	111.03	0.037	0.054834	0.003494	999.40	1.3568	5.75	45.3	1.75	13.8			0.95584	16
111601	15.0	112.18	0.115	0.054919	0.006894	999.13	1.3613	6.25	49.2	1.25	9.8			1.05386	62
121601	17.0	115.28	0.196	0.054855	0.011311	998.80	1.3893	7.75	61	1.25	9.8			1.21653	2
131601	19.0	119.72	0.255	0.055111	0.017430	998.44	1.4329	8.25	65	1.75	13.8			1.32064	2
141601	21.0	125.30	0.341	0.055346	0.029211	998.02	1.4895	8.75	68.9	1.75	13.8			1.52849	2
151601	23.0	128.71	0.377	0.054919	0.038031	997.57	1.5196	8.75	68.9	1.75	13.8			1.69879	2
11901	13.0	112.12	0.065	0.061042	0.001741	999.40	1.3701	5.25	41.3	1.25	9.8			1.08217	1
21901	15.0	112.53	0.094	0.061042	0.003609	999.13	1.3656	6.75	53.1	1.25	9.8			1.14091	16
31901	17.0	114.46	0.128	0.061042	0.007154	998.80	1.3793	7	55.1	1.25	9.8			1.22270	12
41901	19.0	119.68	0.214	0.060945	0.013134	998.44	1.4324	8.75	68.9	1.25	9.8			1.36645	2
51901	22.0	126.99	0.278	0.061234	0.020745	997.80	1.4807	9	70.9	1.25	9.8			1.44450	2
61901	23.0	129.78	0.334	0.061195	0.029125	997.57	1.5323	9.75	76.8	1.25	9.8			1.69184	2
71901	25.0	132.17	0.362	0.060945	0.034003	997.57	1.5499	9.25	72.8	1.25	9.8			1.91966	2

TABLE S42 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	L/D	OUTLET L	L/D	METRE FLOW PATRN L	L/D	PR-GRAD KN/M3	FLOW PATTERN
12101	16.5	101.33	0.439	0.002903	0.001970	998.89	1.2232							0.02920	3
22101	17.5	101.33	0.438	0.002903	0.003879	998.72	1.2190							0.02949	3
32101	19.0	101.33	0.444	0.002903	0.007728	998.44	1.2127							0.03020	3
42101	20.0	101.33	0.457	0.002903	0.011453	998.23	1.2085							0.02992	4
52101	22.0	101.33	0.454	0.002903	0.015230	997.80	1.2003							0.02707	4
62101	24.0	101.33	--	0.002903	0.023968	997.32	1.1922							--	42
72101	24.5	101.33	--	0.002903	0.033505	997.20	1.1902							--	42
82101	25.0	101.33	--	0.002903	0.048438	997.07	1.1882							--	2
102101	12.0	101.33	0.222	0.005121	0.002002	999.52	1.2425							0.03148	3
112101	13.5	101.33	0.222	0.005301	0.004189	999.34	1.2360							0.03262	3
122101	15.0	101.33	--	0.005301	0.008223	999.13	1.2296							--	2
132101	16.5	101.33	--	0.005301	0.010859	998.89	1.2232							--	2
142101	17.5	101.33	--	0.005301	0.018756	998.72	1.2190							--	2

TABLE S43 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	INLET L/D	OUTLET L	OUTLET L/D	METRE FLOW PATRN L	METRE FLOW PATRN L/D	PR-GRAD KN/M3	FLOW PATTERN
152101	18.5	101.33	--	0.005247	0.028567	998.53	1.2148							--	2
162101	20.0	101.33	0.820	0.005247	0.038627	998.23	1.2085							0.07237	2
172101	22.5	101.33	0.815	0.005301	0.048753	997.68	1.1983							0.10019	2
12201	11.0	101.33	0.174	0.007559	0.001987	999.63	1.2469							0.03447	6
22201	13.0	101.33	0.311	0.007559	0.004120	999.40	1.2382							0.04516	62
32201	15.5	101.33	0.434	0.007620	0.008006	999.05	1.2274							0.03803	2
42201	19.0	101.33	0.553	0.007620	0.012705	998.44	1.2127							0.04972	2
52201	21.0	101.33	0.667	0.007620	0.023509	998.02	1.2044							0.07479	2
62201	23.0	101.33	0.779	0.007559	0.035480	997.57	1.1963							0.11422	2
72201	25.0	101.33	0.815	0.007559	0.051504	997.07	1.1882							0.14002	2
92201	15.0	101.33	0.183	0.009869	0.002003	999.13	1.2296							0.05356	6
102201	17.0	101.33	0.302	0.009917	0.004269	998.80	1.2211							0.06125	62
112201	18.0	101.33	0.432	0.009869	0.008809	998.63	1.2169							0.07191	2

TABLE S44 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	L/D	OUTLET L	L/D	METRE FLOW PATRN L	L/D	PR-GRAD KN/M3	FLOW PATTERN
122201	20.0	101.33	0.519	0.009822	0.011991	998.23	1.2085							0.08587	2
132201	21.5	101.33	0.624	0.009774	0.019708	997.91	1.2024							0.08669	2
142201	24.0	101.33	0.767	0.009822	0.036779	997.32	1.1922							0.17058	2
152201	25.0	101.33	0.804	0.009774	0.047605	997.07	1.1982							0.26246	2
12301	9.5	101.33	0.169	0.011492	0.002099	999.77	1.2536							0.06599	6
22301	12.5	101.33	0.238	0.011532	0.004159	999.46	1.2404							0.07520	62
32301	14.5	101.33	0.405	0.011532	0.007997	999.20	1.2317							0.08757	2
42301	16.0	101.33	0.510	0.011532	0.013505	998.97	1.2253							0.11464	2
52301	19.0	101.33	0.612	0.011492	0.023950	998.44	1.2127							0.14256	2
62301	21.0	101.33	0.728	0.011369	0.036546	998.02	1.2044							0.22505	2
72301	25.5	104.91	0.784	0.011286	0.047381	996.94	1.2283	11-75	9-25	1-25	9-8			0.16227	2
92301	11.0	101.33	0.156	0.013789	0.002080	999.63	1.2469							0.07953	6
102301	14.0	101.33	0.249	0.013789	0.004034	999.27	1.2339							0.09307	62

TABLE S45 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	SETTLING LENGTH,L INLET L/D	SETTLING LENGTH,L OUTLET L	SETTLING LENGTH,L OUTLET L/D	METRE FLOW PATRN L	METRE FLOW PATRN L/D	PR-GRAD KN/M3	FLOW PATTERN
112301	15.0	102.38	0.382	0.013823	0.008418	999.13	1.2424							0.11210	2
122301	17.5	103.18	0.498	0.013755	0.013896	998.72	1.2413							0.13537	2
132301	20.0	104.22	0.603	0.013789	0.023755	998.23	1.2431							0.18952	2
142301	23.0	104.99	0.723	0.013755	0.036349	997.57	1.2396	9.25	72.8	3.25	25.6			0.22445	2
152301	25.0	105.79	0.760	0.013755	0.046879	997.07	1.2406							--	2
12601	11.5	102.31	0.149	0.015914	0.002007	999.58	1.2568							0.11422	62
22601	14.0	102.70	0.257	0.015902	0.003998	999.27	1.2506							0.12395	2
32601	15.0	102.84	0.341	0.015873	0.007847	999.13	1.2579							0.14256	2
42601	17.0	103.31	0.461	0.015873	0.012635	998.80	1.2449							0.17090	2
52601	19.0	104.50	0.583	0.015843	0.020534	998.44	1.2507	9.25	72.8	1.75	13.8			0.21688	2
62601	22.0	105.64	0.570	0.015814	0.032926	997.80	1.2515	9.75	76.8	1.25	9.8			0.29546	2
72601	25.0	105.78	0.737	0.015273	0.046069	997.07	1.2522							--	2
102601	11.0	102.78	0.139	0.017474	0.002049	999.63	1.2648	3.25	25.6	1.25	9.8			0.12431	62

TABLE S46 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET		SETTLING LENGTH,L OUTLET		METRE FLOW PATRN		PR-GRAD KN/M3	FLOW PATTERN
								L	L/D	L	L/D	L	L/D		
112601	13.0	102.94	0.236	0.017447	0.003854	999.40	1.2580	3.25	25.6	1.25	9.8			0.14444	2
122601	15.0	103.20	0.332	0.017420	0.007662	999.13	1.2523	3.25	25.6	1.75	13.8			0.16463	2
132601	17.0	103.79	0.433	0.017420	0.012164	998.80	1.2507	6.75	53.1	1.25	9.8			0.18832	2
142601	20.0	104.92	0.552	0.017447	0.020243	998.23	1.2515	9.25	72.8	1.25	9.8			0.24352	2
152601	22.0	106.18	0.682	0.017312	0.037630	997.80	1.2578							--	-2
162601	26.0	108.48	0.719	0.017366	0.050450	996.81	1.2679							--	2
12701	10.5	101.33	--	0.003060	0.049227	999.68	1.2491							--	42
22701	12.0	102.21	0.709	0.003060	0.084559	999.52	1.2534							0.01610	4
32701	14.5	102.87	0.751	0.003060	0.120978	999.20	1.2505							0.03504	4
42701	17.0	103.55	0.809	0.003060	0.158316	998.80	1.2479							0.05214	4
52701	19.0	105.03	0.887	0.003060	0.211641	998.44	1.2571	7.25	57.1	2.75	21.7			0.08885	54
62701	21.0	105.66	0.896	0.003060	0.240542	998.02	1.2560	7.25	57.1	2.75	21.7			0.12605	54
102701	11.0	106.67	0.896	0.003060	0.263998	999.63	1.3127	7.25	57.1	3.75	29.5			0.14710	5

TABLE S47 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L		OUTLET L		METRE FLOW PATRN L		PR-GRAD KN/M3	FLOW PATTERN
								L	L/D	L	L/D	L	L/D		
112701	14.0	107.42	0.913	0.003060	0.293000	999.27	1.3080	5.25	41.3	3.75	29.5			0.17228	5
12801	11.0	103.16	0.836	0.005301	0.046301	999.63	1.2695							0.08486	24
22801	13.0	103.56	0.842	0.005301	0.073733	999.40	1.2655							0.11097	2
13001	11.0	104.76	0.800	0.005388	0.114541	999.63	1.2892	7.25	57.1	3.75	29.5			0.14111	2
23001	17.5	105.58	0.812	0.005336	0.151948	998.72	1.2702	9.25	72.8	2.25	17.7			0.15583	25
33001	19.0	107.06	0.847	0.005301	0.204284	998.44	1.2814	10.25	80.7	2.25	17.7			0.15585	52
10502	11.5	107.73	0.828	0.005559	0.220330	999.58	1.3234	9.25	72.8	2.25	17.7			0.16908	5
20502	15.0	108.46	0.864	0.005559	0.248824	999.13	1.3162	9.25	72.8	2.25	17.7			0.17800	5
30502	17.0	110.53	0.890	0.005643	0.297672	998.80	1.3320	2.25	17.7	5.25	41.3			0.16017	5
10202	10.5	104.33	0.786	0.007559	0.065087	999.68	1.2851	10.25	80.7	1.25	9.8			0.15903	2
20202	13.0	105.39	0.823	0.007496	0.090019	999.40	1.2878	10.25	80.7	1.25	9.8			0.28743	2
30202	17.0	107.65	0.797	0.007496	0.133272	998.80	1.2973	8.75	68.9	1.25	9.8			0.44830	2
40202	19.5	108.79	0.782	0.007496	0.192552	998.36	1.2998							--	52

TABLE S48 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET		SETTLING LENGTH,L OUTLET		METRE FLOW PATRN		PR-GRAD KN/M3	FLOW PATTERN
								L	L/D	L	L/D	L	L/D		
10602	11.0	109.63	0.812	0.007434	0.214424	999.63	1.3491	2.25	17.7	4.75	37.4			0.12762	5
20602	15.0	110.75	0.847	0.007370	0.245321	999.13	1.3439	2.25	17.7	4.25	33.5			0.16678	5
30602	17.0	113.01	0.870	0.007559	0.286914	998.80	1.3620	4.75	37.4	1.25	9.8			0.24853	5
70202	11.0	104.14	0.758	0.009726	0.050039	999.63	1.2816	7.75	61	1.25	9.8			0.17584	2
80202	15.0	106.16	0.806	0.009774	0.080411	999.13	1.2882	10.25	80.7	1.75	13.8			0.45203	2
90202	18.0	108.85	0.737	0.009869	0.108189	998.63	1.3072							--	2
100202	20.5	109.71	0.726	0.009917	0.142860	998.13	1.3063							--	25
110202	22.0	110.38	0.780	0.009822	0.188329	997.80	1.3076	1.25	9.8	2.75	21.7			0.14583	5
120202	23.0	112.10	0.830	0.009678	0.226491	997.57	1.3235	6.75	53.1	2.25	17.7			0.17956	5
10302	10.0	104.93	0.780	0.011971	0.057145	999.72	1.2959	10.75	84.6	1.25	9.8			0.18939	2
20302	12.0	108.19	0.789	0.011813	0.087451	999.52	1.3267							--	2
30302	15.0	111.44	0.691	0.011892	0.130498	999.13	1.3523							--	2
40302	17.0	111.66	0.765	0.011853	0.182023	998.80	1.3456	7.25	57.1	3.25	25.6			0.14972	5

TABLE S49 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	INLET L/D	OUTLET L	OUTLET L/D	METRE FLOW PATRN L	METRE FLOW PATRN L/D	PR-GRAD KN/M3	FLOW PATTERN
10902	11.0	112.75	0.829	0.009793	0.234428	999.63	1.3875	4.25	33.5	1.25	9.8			0.21319	5
20902	13.0	115.17	0.861	0.009726	0.283386	999.40	1.4074	5.75	45.3	1.25	9.8			0.34979	5
30902	15.0	113.80	0.797	0.011853	0.216452	999.13	1.3809	6.25	49.2	2.25	17.7			0.22985	5
40902	17.0	114.92	0.818	0.012010	0.234859	998.80	1.3849	6.25	49.2	1.25	9.8			0.29238	5
50902	18.0	117.89	0.868	0.011853	0.285563	998.63	1.4158	5.25	41.3	1.25	9.8			0.47944	5
60302	9.0	106.04	0.754	0.013686	0.055117	999.80	1.3142	9.75	76.8	1.25	9.8			0.31496	2
70302	13.0	108.79	0.736	0.013686	0.081225	999.40	1.3294							--	2
80302	16.0	112.84	0.668	0.013686	0.120424	998.97	1.3645							--	2
90302	18.0	112.21	0.729	0.013823	0.168557	998.63	1.3476	1.5	11.8	1.25	9.8			0.19068	5
100302	20.0	114.48	0.781	0.013789	0.203606	998.23	1.3654	7.25	57.1	1.25	9.8			0.23643	5
110302	21.0	116.69	0.817	0.013549	0.236611	998.02	1.3871	7.25	57.1	1.25	9.8			0.33585	5
120302	21.5	120.19	0.857	0.013686	0.281711	997.91	1.4263	3.25	25.6	1.25	9.8			0.59626	5
10402	10.0	106.66	0.729	0.015454	0.056528	999.72	1.3172	10.5	82.7	1.25	9.8			0.29763	2

TABLE S50 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	L/D	OUTLET L	L/D	METRE FLOW PATRN L	L/D	PR-GRAD KN/M3	FLOW PATTERN
20402	13.0	110.72	0.686	0.015724	0.083329	999.40	1.3530							--	2
30402	16.0	113.36	0.636	0.015635	0.116469	998.97	1.3708							--	2
40402	18.5	112.70	0.683	0.015724	0.151364	998.53	1.3512	2.25	17.7	1.75	13.8			0.17707	52
11002	14.5	115.05	0.750	0.015605	0.185821	999.20	1.3986	5.75	45.3	1.25	9.8			0.28733	5
21002	17.0	116.60	0.782	0.015695	0.208924	998.80	1.4052	6.25	49.2	1.25	9.8			0.37501	5
31002	18.0	119.77	0.820	0.015784	0.239875	998.63	1.4384	6.25	49.2	1.25	9.8			0.59109	5
41002	19.5	123.46	0.867	0.015575	0.286660	998.34	1.4751	6.25	49.2	3.25	25.6			0.81831	5
60402	11.0	107.21	0.710	0.017474	0.050908	999.63	1.3193	11.25	88.6	1.25	9.8			0.37920	2
70402	14.5	111.98	0.632	0.017366	0.081007	999.20	1.3612							--	2
80402	17.0	115.04	0.615	0.017312	0.105923	998.80	1.3864							--	2
90402	19.0	114.38	0.664	0.017312	0.132183	998.44	1.3689	1.25	9.8	4.25	33.5			0.18553	25
11702	12.0	116.06	0.712	0.017312	0.174896	999.52	1.4233	6.25	49.2	3.75	29.5			0.29489	25
21702	14.5	118.23	0.753	0.017312	0.203919	999.20	1.4372	7.25	57.1	1.25	9.8			0.44332	52

TABLE S51 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	INLET L/D	OUTLET L	OUTLET L/D	METRE FLOW PATRN L	L/D	PR-GRAD KN/M3	FLOW PATTERN
31702	16.5	121.48	0.794	0.017366	0.235195	998.89	1.4665	7.75	61	1.25	9.8			0.69078	5
41702	18.5	124.29	0.835	0.017500	0.265767	998.53	1.4901	5.25	41.3	1.25	9.8			0.93750	5
11802	12.0	107.42	0.687	0.018781	0.047885	999.52	1.3173	11.25	88.6	1.25	9.8			0.40027	2
21802	16.5	114.57	0.630	0.018590	0.082606	998.89	1.3831							--	2
31802	20.5	115.83	0.651	0.018715	0.112539	998.13	1.3792							--	2
41802	23.0	116.58	0.698	0.018903	0.158089	997.57	1.3764	2.25	17.7	4.25	33.5			0.36130	25
51802	24.0	118.92	0.753	0.018781	0.193581	997.32	1.3993	7.25	57.1	1.25	9.8			0.46292	52
61802	24.5	120.40	0.773	0.018653	0.214230	997.20	1.4143	7.25	57.1	1.25	9.8			0.59859	5
81802	14.5	110.81	0.641	0.024388	0.050656	999.20	1.3470	12.25	96.5	1.25	9.8			0.58450	2
91802	16.5	118.42	0.508	0.024146	0.076648	998.89	1.4295							--	2
101802	18.5	116.99	0.602	0.024194	0.106786	998.53	1.4025	3.75	29.5	5.75	45.3			0.38093	2
111802	22.0	119.45	0.681	0.023999	0.145059	997.80	1.4150	6.75	53.1	4.25	33.5			0.51337	2
121802	23.5	121.80	0.709	0.024291	0.172116	997.45	1.4356	7.25	57.1	1.25	9.8			0.78218	25

TABLE S52 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET		OUTLET		METRE FLOW PATRN		PR-GRAD KN/M3	FLOW PATTERN
								L	L/D	L	L/D	L	L/D		
12702	11.0	125.91	0.750	0.024388	0.188572	999.63	1.5495	3.75	29.5	2.25	17.7			1.18988	25
22702	14.0	129.27	0.783	0.024339	0.214222	999.27	1.5741	5.25	41.3	1.75	13.8			1.41800	25
32702	16.0	133.46	0.798	0.024484	0.245571	998.97	1.6139	5.25	41.3	1.75	13.8			1.71450	52
12002	10.0	116.06	0.517	0.028848	0.053294	999.72	1.4332							--	2
22002	13.0	118.38	0.552	0.028766	0.084659	999.40	1.4466	3.25	25.6	6.25	49.2			0.46819	2
32002	15.5	120.16	0.595	0.028848	0.108414	998.89	1.4506	3.75	29.5	4.25	33.5			0.64482	2
42002	18.5	122.09	0.546	0.028766	0.126833	998.53	1.4637	3.75	29.5	4.25	33.5			0.79282	2
10303	11.0	123.83	0.714	0.028479	0.161119	999.63	1.5239	4.25	33.5	3.75	29.5			1.40095	2
20303	14.0	131.77	0.747	0.029212	0.180953	999.27	1.6045	5.25	41.3	4.25	33.5			1.56456	2
30303	16.0	135.92	0.773	0.029172	0.208611	998.97	1.6437	5.25	41.3	3.75	29.5			1.98840	25
40303	18.5	140.01	0.805	0.028520	0.260191	998.53	1.6786	5.75	45.3	3.75	29.5			2.23242	52
12302	11.0	116.60	0.488	0.032597	0.046555	999.63	1.4349							--	2
22302	13.0	120.18	0.518	0.032453	0.078193	999.40	1.4686	3.75	29.5	6.25	49.2			0.56217	2

TABLE S53 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST	TEMP	P MEAN	VOID	WATER FLOW	AIR FLOW	DENSITY	DENSITY	SETTLING LENGTH,L				METRE		PR-GRAD	FLOW
RUN			FRCTN	RATE	RATE	WATER	AIR	INLET		OUTLET		FLOW PATRN			
NO	C	KN/M2		M3/SEC	M3/SEC	KG/M3	KG/M3	L	L/D	L	L/D	L	L/D	KN/M3	PATTERN
32302	16.0	123.52	0.593	0.032705	0.104604	998.97	1.4937	4.25	33.5	4.25	33.5			1.03367	2
42302	19.0	127.05	0.649	0.032850	0.128283	998.46	1.5206	4.25	33.5	4.25	33.5			1.28533	2
52302	22.0	131.42	0.687	0.032777	0.145869	997.80	1.5569	4.75	37.4	2.25	17.7			1.66259	2
62302	23.0	134.83	0.716	0.032741	0.175767	997.57	1.5918	5.25	41.3	3.75	29.5			1.97703	2
72302	23.5	140.67	0.760	0.032525	0.203175	997.45	1.6580	5.25	41.3	3.75	29.5			2.39376	25
102302	12.0	119.59	0.468	0.039361	0.046679	999.52	1.4665							--	2
112302	14.5	123.92	0.503	0.039361	0.070583	999.20	1.5064	5.25	41.3	5.75	45.3			0.93397	2
122302	17.0	129.23	0.588	0.039300	0.098375	998.80	1.5573	4.25	33.5	3.75	29.5			1.47100	2
132302	19.5	133.69	0.635	0.039390	0.118942	998.34	1.5973	5.25	41.3	3.75	29.5			1.91018	2
142302	21.0	141.06	0.696	0.039420	0.141600	998.02	1.6768	5.25	41.3	3.75	29.5			2.59505	2
152302	23.0	145.47	0.718	0.039479	0.164154	997.57	1.7174	5.75	45.3	3.75	29.5			2.91923	2
162302	24.0	148.13	0.744	0.039449	0.182277	997.32	1.7430	5.75	45.3	3.75	29.5			3.22729	2
12402	10.0	120.01	0.429	0.045664	0.041223	999.72	1.4821	5.75	45.3	5.75	45.3			1.06867	2

TABLE S54 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L				METRE		PR-GRAD KN/M3	FLOW PATTERN
								INLET		OUTLET		FLOW PATRN			
								L	L/D	L	L/D	L	L/D		
22402	13.5	128.75	0.505	0.045224	0.070156	999.34	1.5705	3.75	29.5	4.25	33.5			1.51187	2
32402	16.5	135.36	0.581	0.045146	0.097850	998.89	1.6340	7.25	57.1	3.75	29.5			2.09754	2
42402	20.5	142.01	0.644	0.045172	0.119646	998.13	1.6910	4.75	37.4	3.75	29.5			2.75133	2
52402	23.0	151.06	0.681	0.045328	0.146012	997.57	1.7834	5.25	41.3	3.75	29.5			3.47691	2
72402	11.0	126.11	0.420	0.050212	0.044862	999.63	1.5519	3.25	25.6	3.75	29.5			1.45432	2
82402	14.5	133.32	0.505	0.050224	0.068818	999.20	1.6206	3.75	29.5	3.75	29.5			1.94869	2
92402	18.5	141.41	0.576	0.050013	0.092676	998.53	1.6953	5.25	41.3	3.25	25.6			2.72181	2
12502	12.0	127.85	0.371	0.055005	0.039879	999.52	1.5678	3.25	25.6	3.75	29.5			1.47100	2
22502	14.0	135.94	0.452	0.055069	0.061371	999.27	1.6554	4.25	33.5	3.75	29.5			2.18366	2
32502	19.0	146.09	0.573	0.055005	0.089728	998.44	1.7485	5.25	41.3	3.75	29.5			3.16178	2
12602	11.5	130.28	0.362	0.059461	0.037582	999.58	1.6004	0.75	5.9	4.5	35.4			1.79902	2
22602	19.0	141.91	0.507	0.058485	0.067042	998.44	1.6984	4.25	33.5	3.5	27.6			2.66960	2
32602	22.5	148.35	0.540	0.059126	0.084258	997.68	1.7344	4.25	33.5	3.75	29.5			3.24637	2

TABLE S55 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	L/D	OUTLET L	L/D	METRE FLOW PATRN L	L/D	PR-GRAD KN/M3	FLOW PATTERN
12806	18.0	102.89	0.211	0.019151	0.002002	998.63	1.2357					6	27.8	0.01368	3
22806	19.5	103.98	0.214	0.019151	0.004077	998.34	1.2424					6	27.8	0.01125	3
32806	20.5	104.91	0.215	0.019029	0.008665	998.13	1.2492					8	37.1	0.01040	4
42806	23.0	105.03	0.223	0.019029	0.012826	997.57	1.2400							0.00940	42
52806	24.0	105.87	0.266	0.019087	0.021485	997.32	1.2457							0.01125	42
62806	26.0	106.46	0.281	0.019029	0.028933	996.81	1.2443					10	46.3	0.01097	2
72806	27.0	107.24	0.371	0.019029	0.041750	996.54	1.2492					13	60.2	0.02080	2
12906	18.0	103.82	0.102	0.025099	0.002165	998.63	1.2468					5	23.2	0.04088	3
22906	20.0	105.29	0.116	0.025005	0.004094	998.23	1.2558					9	41.7	0.05733	4
32906	21.0	106.44	0.148	0.025054	0.009972	998.02	1.2653							0.04172	42
42906	22.5	106.71	0.207	0.025005	0.017769	997.68	1.2520					12	55.6	0.04399	2
52906	24.0	107.12	0.295	0.024437	0.026626	997.32	1.2604					15	69.5	0.04740	2
62906	26.0	108.33	0.381	0.024437	0.038108	996.81	1.2661					15	69.5	0.06017	2

TABLE S56 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	L/D	OUTLET L	L/D	METRE FLOW PATRN L	L/D	PR-GRAD KN/M3	FLOW PATTERN
72906	27.0	108.55	0.392	0.024437	0.047315	996.54	1.2645					15	69.5	0.06954	2
92906	18.0	104.43	0.035	0.029494	0.001979	998.63	1.2542					12	55.6	0.04995	36
102906	19.5	106.09	0.060	0.029453	0.003931	998.34	1.2676							0.04683	36
112906	21.5	107.45	0.125	0.029373	0.009467	997.91	1.2751					10	46.3	0.04428	62
122906	23.0	108.10	0.207	0.029494	0.016293	997.57	1.2763					12	55.6	0.05478	2
132906	24.0	109.14	0.284	0.029532	0.025365	997.32	1.2842					14	64.9	0.06045	2
142906	25.0	109.93	0.334	0.029411	0.034558	997.07	1.2891					14	64.9	0.07351	2
152906	26.5	110.51	0.412	0.029213	0.044823	996.67	1.2895					14	64.9	0.08912	2
13036	18.5	105.41	0.028	0.032776	0.001980	998.53	1.2638							0.04768	64
23006	20.0	106.81	0.057	0.032704	0.003824	998.23	1.2739					5	23.2	0.04598	6
33006	20.5	108.18	0.123	0.032598	0.008820	998.13	1.2881					8	37.1	0.04456	62
43006	23.0	109.30	0.204	0.032776	0.015215	997.37	1.2904					12	55.6	0.05080	2
53006	25.5	110.66	0.303	0.032813	0.025033	996.94	1.2955					14	65.	0.05733	2

TABLE S57 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET		OUTLET		METRE FLOW PATRN		PR-GRAD KN/M3	FLOW PATTERN
								L	L/D	L	L/D	L	L/D		
63006	27.0	111.47	0.354	0.032850	0.033907	996.54	1.2984					14	65	0.06216	2
73006	28.0	112.61	0.431	0.032742	0.046035	996.26	1.3074					13	60	0.08912	2
93006	18.5	107.89	0.022	0.039657	0.002011	998.53	1.2934					4	18.5	0.06092	6
103006	20.0	109.18	0.055	0.039657	0.003983	998.23	1.3022					6	27.8	0.05499	6
113006	22.0	111.26	0.118	0.039480	0.008996	997.80	1.3180					8	37.1	0.06557	26
123006	24.0	112.86	0.188	0.039568	0.016001	997.32	1.3279					14	64.9	0.07995	2
133006	26.0	114.42	0.272	0.039480	0.023960	996.81	1.3373					15	69.5	0.09222	2
143006	29.0	115.22	0.396	0.039091	0.034887	995.97	1.3333					15	69.5	0.12902	2
10107	19.0	109.90	0.019	0.044570	0.001617	998.44	1.3153	2	9.3			5	23.2	0.04345	6
20107	23.0	112.07	0.050	0.044832	0.003645	997.57	1.3232	3	13.9			6	27.8	0.04203	62
30107	26.5	115.20	0.123	0.044646	0.009790	996.67	1.3442	4	18.5			6	27.8	0.04834	2
40107	30.0	117.08	0.208	0.044807	0.016014	995.67	1.3504	6	27.8			15	69.5	0.07144	2
60107	21.5	118.17	0.264	0.044780	0.023081	997.91	1.4023	7	32.4			14	64.9	0.10973	2

TABLE S58 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	L/D	OUTLET L	L/D	METRE FLOW PATRN L	L/D	PR-GRAD KN/M3	FLOW PATTERN
70107	23.5	120.06	0.280	0.044727	0.031838	997.45	1.4150	10	46.3			15	69.5	0.18710	2
80107	26.5	122.16	0.276	0.044859	0.042116	996.67	1.4253	13	60.2					0.36943	2
90107	28.5	112.69	0.028	0.050782	0.001893	996.11	1.3062	1	4.6			4	18.5	0.05834	6
100107	30.0	114.94	0.046	0.050521	0.003834	995.67	1.3256	4	18.5			5	23.2	0.06129	62
10207	20.0	117.42	0.098	0.050177	0.008581	998.23	1.4005	5	23.2			10	46.3	0.06350	2
20207	23.5	119.88	0.169	0.050177	0.015010	997.45	1.4130	7.5	34.7			12	55.6	0.08801	2
30207	25.5	122.13	0.178	0.050224	0.021896	996.94	1.4298	10.5	48.6			14	64.9	0.13621	2
40207	27.0	124.28	0.230	0.050504	0.030680	996.54	1.4477							--	2
50207	29.5	128.26	0.303	0.050412	0.040637	995.82	1.4817							--	2
70207	20.0	115.49	0.023	0.056281	0.001983	998.23	1.3775	1	4.6			6	27.8	0.06871	6
80207	23.0	117.75	0.048	0.056377	0.003986	997.57	1.3902	1	4.6			6	27.8	0.06960	62
90207	25.0	121.18	0.113	0.056397	0.008606	997.07	1.4211	7	32.4					0.09490	2
100207	27.0	123.63	0.176	0.056273	0.014098	996.54	1.4401	10	46.3			15	69.5	0.12340	2

TABLE S59 PRESSURE DROP, SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	SETTLING LENGTH,L INLET L/D	OUTLET L	OUTLET L/D	METRE FLOW PATRN L	METRE FLOW PATRN L/D	PR-GRAD KN/M3	FLOW PATTERN
110207	28.5	126.38	0.174	0.056042	0.023131	996.11	1.4648							--	2
120207	30.0	130.10	0.257	0.056502	0.030187	995.67	1.5004							--	2
130207	30.0	134.80	--	0.056377	0.038332	995.67	1.5546							--	42
10507	20.0	117.61	0.013	0.061215	0.001607	998.23	1.4028	1	4-6			7	32-4	0.07793	6
20507	22.0	119.90	0.042	0.061099	0.003639	997.80	1.4204	1	4-6			13	60-2	0.07898	62
30507	24.0	124.02	0.099	0.060674	0.008311	997.32	1.4593	7	32-4			12	55-6	0.08229	2
40507	26.0	127.24	0.161	0.060887	0.014026	996.81	1.4871	10	46-3			14	64-9	0.16758	2
50507	28.0	131.20	0.165	0.061060	0.022633	996.26	1.5232							--	2
60507	29.0	134.98	0.247	0.061157	0.030015	995.97	1.5619							--	24
70507	31.5	139.06	0.298	0.061560	0.037830	995.20	1.5959							--	42
90507	20.5	101.83	0.710	0.003060	0.002197	998.13	1.2124					2	9-3	0.00185	3
100507	22.0	101.96	0.710	0.003210	0.004423	997.80	1.2079					8	37-1	0.00256	3
110507	23.0	102.09	0.713	0.003121	0.010533	997.57	1.2053					8	37-1	0.00456	3

TABLE S60 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	INLET L/D	OUTLET L	OUTLET L/D	METRE FLOW PATRN L	METRE FLOW PATRN L/D	PR-GRAD KN/M3	FLOW PATTERN
120507	27.0	102.09	0.711	0.003121	0.018163	996.54	1.1892					8	37.1	0.00385	3
130507	28.0	102.36	0.717	0.003030	0.031074	996.26	1.1884					10	46.3	0.00328	3
140507	29.0	101.34	0.708	0.003060	0.038926	995.97	1.1726					12	55.6	0.00328	3
150507	30.0	102.90	0.717	0.003121	0.049853	995.67	1.1868					13	60.2	0.00299	34
10607	20.5	101.58	0.625	0.005139	0.002099	998.13	1.2095					3	13.9	0.00499	3
20607	24.0	101.85	0.626	0.005103	0.004305	997.32	1.1985					4	18.5	0.00285	3
30607	25.5	102.12	0.617	0.005247	0.010656	996.94	1.1955					6	27.8	0.00214	3
40607	28.0	102.38	0.619	0.005283	0.017114	996.26	1.1887					8	37.1	0.00299	3
50607	29.5	102.65	0.620	0.005301	0.028997	995.82	1.1858					11	51	0.00527	34
60607	30.0	102.79	0.621	0.005301	0.037338	995.67	1.1854					11	51	0.00584	34
70607	31.0	103.05	0.623	0.005283	0.050748	995.36	1.1846					12	55.6	0.00584	34
90607	22.0	101.84	0.542	0.007434	0.002133	997.80	1.2065					3	13.9	0.00071	3
100607	23.0	102.11	0.537	0.007521	0.004491	997.57	1.2055					10	46.3	0.00385	3

TABLE S61 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	SETTLING LENGTH,L INLET L/D	OUTLET L	OUTLET L/D	METRE FLOW PATRN L	METRE FLOW PATRN L/D	PR-GRAD KN/M3	FLOW PATTERN
110607	25.0	102.38	0.540	0.007546	0.010534	997.07	1.2007					12	55.6	0.00071	3
120607	26.0	102.66	0.539	0.007509	0.017044	996.81	1.1998					10	46.3	0.00057	34
130607	29.0	102.92	0.542	0.007446	0.027804	995.97	1.1910					10	46.3	0.00100	4
140607	30.3	103.06	0.540	0.007559	0.034914	995.58	1.1874					12	55.6	0.00085	4
150607	33.0	103.58	0.544	0.007583	0.049658	994.72	1.1829					8	37.1	0.00114	4
10707	19.5	101.60	0.461	0.009707	0.002071	998.34	1.2139					3	13.9	0.02137	3
20707	21.5	102.14	0.461	0.009774	0.004556	997.91	1.2120					11	51	0.02208	3
30707	23.0	102.42	0.460	0.009803	0.010417	997.57	1.2092					11	51	0.01895	3
40707	25.5	102.84	0.459	0.009725	0.017344	996.94	1.2039					12	55.6	0.01624	34
50707	26.5	103.24	0.464	0.009726	0.028234	996.67	1.2046					12	55.6	0.01553	4
60707	28.0	103.51	0.464	0.009716	0.037460	996.26	1.2018					13	60.2	0.01439	4
70707	29.0	103.92	0.468	0.009736	0.048813	995.97	1.2025					14	64.9	0.01339	4
90707	20.5	101.72	0.406	0.011492	0.002183	998.13	1.2112					3	13.9	0.03049	3

TABLE S62 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	INLET L/D	OUTLET L	OUTLET L/D	METRE FLOW PATRN L	METRE FLOW PATRN L/D	PR-GRAD KN/M3	FLOW PATTERN
100707	22.0	102.27	0.409	0.011484	0.004335	997.80	1.2115					7	32.4	0.02920	3
110707	23.0	102.68	0.410	0.011451	0.010341	997.57	1.2123					12	55.6	0.02849	3
120707	25.0	103.08	0.409	0.011467	0.017670	997.07	1.2088					11	51.0	0.02849	4
130707	26.0	103.47	0.412	0.011426	0.027239	996.81	1.2094					10	46.3	0.02920	4
140707	27.5	103.87	0.406	0.011581	0.037718	996.40	1.2080					10	46.3	0.02949	4
150707	28.0	104.29	0.404	0.011654	0.050315	996.26	1.2108					10	46.3	0.02892	4
10807	20.0	101.75	0.346	0.013755	0.002183	998.23	1.2136					4	18.5	0.03276	3
20807	21.5	102.56	0.350	0.013823	0.004302	997.91	1.2170					12	55.6	0.03276	3
30807	23.0	103.10	0.350	0.013823	0.010435	997.57	1.2172					12	55.6	0.03362	34
40807	24.0	103.37	0.351	0.013823	0.017361	997.32	1.2164					10	46.3	0.03390	4
50807	25.5	103.79	0.354	0.013836	0.027916	996.94	1.2151					8	37.1	0.03262	4
60807	26.5	104.26	0.355	0.013809	0.038562	996.57	1.2165					6	27.8	0.03248	4
70807	28.0	104.81	0.362	0.013755	0.050782	996.26	1.2168					6	27.8	0.03177	4

TABLE S63 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	INLET L/D	OUTLET L	OUTLET L/D	METRE FLOW PATRN L	METRE FLOW PATRN L/D	PR-GRAD KN/M3	FLOW PATTERN
90807	21.0	101.81	0.292	0.015814	0.002128	998.02	1.2101					5	23.2	0.03148	3
100807	22.5	102.89	0.295	0.015873	0.004266	997.68	1.2169					15	69.5	0.03177	3
110807	24.0	103.43	0.299	0.015814	0.010453	997.32	1.2171					14	64.9	0.03077	34
120807	25.0	103.97	0.298	0.015796	0.017144	997.07	1.2193					8	37.1	0.03205	4
130807	26.5	104.51	0.301	0.015843	0.027611	996.67	1.2195					6	27.8	0.03134	4
140807	28.0	104.92	0.303	0.015695	0.036284	996.26	1.2182					6	27.8	0.03006	42
150807	30.0	105.23	--	0.015695	0.049016	995.67	1.2138							--	42
10907	21.5	101.90	0.249	0.017377	0.002147	997.91	1.2092					3	13.9	0.03547	3
20907	23.0	103.13	0.245	0.017607	0.004397	997.57	1.2176					13	60.2	0.03618	3
30907	24.0	103.94	0.246	0.017302	0.010478	997.32	1.2231					10	46.3	0.03462	4
40907	25.0	104.48	0.249	0.017527	0.016987	997.07	1.2253					6	27.8	0.03533	4
50907	26.5	105.02	--	0.017580	0.027799	996.67	1.2254							--	2
60907	27.0	105.00	--	0.017474	0.038069	996.54	1.2231							--	2

TABLE S64 PRESSURE DROP, SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L METRES						PR-GRAD KN/M3	FLOW PATTERN
								INLET		OUTLET		FLOW PATRN			
								L	L/D	L	L/D	L	L/D		
70907	29.0	105.40	--	0.017554	0.049054	995.97	1.2197							--	2
11207	22.5	102.55	0.727	0.002822	0.049733	997.68	1.2128					10	46.3	0.00356	34
21207	24.0	102.95	0.730	0.002597	0.093775	997.32	1.2114					6	27.8	0.00399	4
31207	25.5	103.49	0.729	0.003210	0.130190	996.94	1.2116					6	27.8	0.00513	4
41207	26.5	104.53	0.744	0.003180	0.192187	996.67	1.2197					13	60.2	0.01040	4
51207	27.0	105.21	0.771	0.003121	0.232484	996.54	1.2255					14	64.9	0.01026	4
61207	27.5	106.01	0.798	0.003060	0.271770	996.40	1.2328					16	74.1	0.01325	4
71207	27.0	106.68	0.856	0.003296	0.315739	996.54	1.2427					16	74.1	0.01724	4
11307	21.5	103.06	0.605	0.005353	0.052367	997.91	1.2230					14	64.9	0.00228	34
21307	23.5	103.74	0.617	0.005475	0.103322	997.45	1.2227					12	55.6	0.00356	4
31307	24.5	104.54	0.626	0.005388	0.131346	997.20	1.2280					15	69.5	0.00527	4
41307	25.5	105.35	0.661	0.005406	0.183061	996.94	1.2333					16	74.1	0.00826	4
51307	26.0	106.42	0.693	0.005509	0.220120	996.81	1.2439					16	74.1	0.01062	4

TABLE S65 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET		OUTLET		METRE FLOW PATRN		PR-GRAD KN/M3	FLOW PATTERN
								L	L/D	L	L/D	L	L/D		
61307	27.0	107.08	0.725	0.005388	0.255407	996.54	1.2474					14	64.9	0.01453	4
71307	27.0	108.32	0.811	0.005371	0.309829	996.54	1.2618					15	69.5	0.02009	4
91307	21.0	103.33	0.541	0.007583	0.050265	998.02	1.2282							--	34
101307	23.0	104.13	0.546	0.007471	0.093177	997.57	1.2294					13	60.2	0.00185	4
111307	24.0	104.92	0.567	0.007620	0.131320	997.32	1.2346					13	60.2	0.00553	4
121307	25.0	106.28	0.609	0.007620	0.175938	997.07	1.2463					16	74.1	0.00584	4
131307	26.0	107.35	0.654	0.007669	0.214572	996.81	1.2546					16	74.1	0.00997	4
141307	26.0	108.32	0.730	0.007681	0.255726	996.81	1.2660					16	74.1	0.01838	4
151307	26.0	109.62	0.779	0.007657	0.296131	996.81	1.2812					16	74.1	0.02237	4
11407	20.5	103.76	0.456	0.009774	0.051036	998.13	1.2354					12	55.6	0.02635	4
21407	22.5	104.99	0.471	0.009726	0.095006	997.68	1.2417					8	37.1	0.02080	4
31407	24.0	106.50	0.547	0.009726	0.141798	997.32	1.2532					14	64.9	0.01553	4
41407	25.0	107.18	0.561	0.009726	0.166369	997.07	1.2569					16	74.1	0.01610	4

TABLE S66 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	L/D	OUTLET L	L/D	METRE FLOW PATRN L	L/D	PR-GRAD KN/M3	FLOW PATTERN
51407	26.0	108.20	0.663	0.009841	0.216729	996.81	1.2646							--	4
61407	26.0	110.12	0.690	0.009888	0.245900	996.81	1.2871					16	74.1	0.02308	4
81407	22.0	104.04	0.408	0.011332	0.049256	997.80	1.2325					6	27.8	0.02521	4
91407	23.5	105.32	0.427	0.011475	0.088994	997.45	1.2413					16	74.1	0.02251	4
101407	24.5	106.39	0.504	0.011451	0.132794	997.20	1.2497					16	74.1	0.02080	4
111407	27.0	108.41	0.574	0.011549	0.184082	996.54	1.2628					14	64.9	0.01866	4
121407	27.5	110.31	0.640	0.011532	0.218441	996.40	1.2828					14	64.9	0.02237	4
131407	28.0	111.58	0.713	0.011451	0.253199	996.26	1.2955							0.02650	4
141407	28.0	113.92	0.770	0.011410	0.301600	996.26	1.3226							0.03077	4
11507	21.0	104.77	0.347	0.013735	0.050171	998.02	1.2453					8	37.1	0.02949	4
21507	22.5	105.89	0.415	0.013721	0.092994	997.68	1.2522							0.03199	42
131507	24.0	106.31	0.475	0.013576	0.137672	997.32	1.2509							0.03120	42
41507	25.0	109.48	0.575	0.013480	0.175398	997.07	1.2839					13	60.2	0.02151	42

TABLE S67 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	INLET L/D	OUTLET L	OUTLET L/D	METRE FLOW PATRN L	METRE FLOW PATRN L/D	PR-GRAD KN/M3	FLOW PATTERN
51507	26.0	101.43	0.616	0.013741	0.231734	996.81	1.1855							0.02051	4
61507	27.0	113.62	0.685	0.013734	0.248510	996.54	1.3236							0.03049	44
71507	27.0	115.96	0.746	0.013755	0.287400	996.54	1.3507							0.03333	44
92007	25.0	105.01	0.303	0.015837	0.048940	997.07	1.2315							0.03162	42
102007	26.0	106.47	--	0.015808	0.081709	996.81	1.2444							--	-2
82807	20.0	122.91	0.216	0.047158	0.043043	998.23	1.4660	13	66-2			16	74.1	0.35431	2
92807	22.0	130.63	0.387	0.046682	0.075997	997.80	1.5475							--	44
102807	24.0	135.14	0.459	0.046354	0.098950	997.32	1.5901					16	74.1	--	44
112807	25.0	142.98	0.544	0.045740	0.135903	997.07	1.6767					16	74.1	0.00271	44
122807	26.0	147.70	0.580	0.045405	0.158048	996.81	1.7263					16	74.1	0.01581	44
12907	20.0	125.04	0.243	0.049684	0.040072	998.23	1.4914					16	74.1	--	2
22907	22.0	133.95	0.408	0.050059	0.059596	997.80	1.3869					16	74-1	--	44
32907	23.0	142.75	0.487	0.050573	0.107784	997.57	1.6854					16	74-1	--	44

TABLE S68 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	INLET L/D	OUTLET L	OUTLET L/D	METRE FLOW PATRN L	METRE FLOW PATRN L/D	PR-GRAD KN/M3	FLOW PATTERN
42907	24.0	146.58	0.512	0.050317	0.124830	997.32	1.7248	2	9-3			16	74.1	--	4
52907	25.0	151.82	0.556	0.049919	0.146817	997.07	1.7804	2	9.3			16	74-1	0.01467	4
72907	21.5	130.15	0.277	0.054962	0.038874	997.91	1.5444							--	2
82907	24.0	138.66	0.407	0.054597	0.072306	997.32	1.6316					16	74-1	--	44
92907	25.5	147.81	0.475	0.054920	0.106263	996.94	1.7305					16	74-1	--	44
102907	26.5	153.63	0.514	0.054898	0.127860	996.67	1.7928	3	13-9			16	74.1	0.01311	4
13007	21.5	136.02	0.292	0.059322	0.041446	997.91	1.6141					16	74.1	--	44
23007	23.5	145.05	0.398	0.059500	0.072061	997.45	1.7097					16	74.1	--	44
33007	25.5	150.75	0.470	0.059343	0.096661	996.94	1.7649					16	74.1	--	44
43007	26.5	158.63	0.511	0.059382	0.119338	996.67	1.8509	2	9-3			16	74.1	0.00598	4
112007	27.0	108.68	--	0.015754	0.130620	996.34	1.2660							--	2
122007	28.0	111.49	0.558	0.015647	0.179597	996.26	1.2943					14	64-9	0.02023	44
132007	28.5	113.12	0.621	0.015581	0.212706	996.11	1.3112					15	69-5	0.01880	44

TABLE S69 PRESSURE DROP, SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET		OUTLET		METRE FLOW PATRN		PR-GRAD KN/M3	FLOW PATTERN
								L	L/D	L	L/D	L	L/D		
142007	28.0	115.01	0.688	0.015551	0.249260	996.26	1.3352							0.02151	44
152007	28.0	113.77	0.734	0.015521	0.290072	996.26	1.3209							0.03291	44
12107	21.0	105.01	--	0.017328	0.047119	998.02	1.2483					14	64.9	--	2
22107	22.0	108.68	--	0.017393	0.089331	997.80	1.2875					14	64.9	--	2
32107	24.5	103.68	--	0.017328	0.140283	997.20	1.2766					16	74.1	--	2
42107	25.5	111.49	0.523	0.017398	0.168475	996.94	1.3032					16	74.1	--	24
52107	26.5	113.73	0.638	0.017441	0.210425	996.67	1.3270					16	74.1	0.01681	44
62107	26.5	116.02	0.676	0.017350	0.239246	996.67	1.3537					16	74.1	0.02202	44
72107	27.0	119.95	0.723	0.017280	0.277363	996.34	1.3972					16	74.1	0.02365	44
132207	20.0	104.95	--	0.018716	0.048662	998.23	1.2518					14	64.9	--	2
142207	22.0	106.47	--	0.018781	0.081822	997.80	1.2613					16	74.1	--	2
152207	24.5	108.68	0.457	0.018651	0.137520	997.20	1.2766					16	74.1	--	2
162207	25.5	113.16	0.562	0.018525	0.178969	996.94	1.3248					16	74.1	0.00783	44

TABLE S70 PRESSURE DROP, SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	INLET L/D	OUTLET L	OUTLET L/D	METRE FLOW PATRN L	METRE FLOW PATRN L/D	PR-GRAD KN/M3	FLOW PATTERN
172207	26.5	113.69	0.610	0.013525	0.208570	996.67	1.3266					16	74.1	0.01567	44
182207	27.0	118.39	0.676	0.018716	0.240893	996.54	1.3791					15	69.5	0.02123	44
192207	26.5	121.76	0.717	0.018651	0.271068	996.57	1.4207					16	74.1	0.02564	44
102307	21.0	105.25	--	0.024483	0.053308	998.02	1.2511							--	2
12607	20.0	101.33	--	0.024723	0.086850	998.23	1.2085							--	2
22607	22.5	115.63	0.434	0.024483	0.125117	997.68	1.3675							--	2
32607	24.0	117.02	0.533	0.024291	0.164173	997.32	1.3769							0.00085	44
42607	25.0	120.21	0.598	0.024194	0.191029	997.07	1.4097							0.01595	44
62607	23.0	111.48	0.427	0.028767	0.048571	997.57	1.3161	7	32.4			16	74.1	0.04767	2
72607	25.5	115.62	0.427	0.029091	0.083092	996.94	1.3536							--	2
82607	27.0	120.47	0.460	0.028930	0.116130	996.56	1.4033							--	2
92607	29.5	122.96	0.531	0.028849	0.155823	995.82	1.4205					16	74.1	0.02554	44
102607	29.5	124.78	0.617	0.028562	0.192963	995.82	1.4415					16	74.1	0.02214	44

TABLE S71 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET		OUTLET		METRE FLOW PATRN		PR-GRAD KN/M3	FLOW PATTERN
								L	L/D	L	L/D	L	L/D		
112607	29.5	131.82	0.660	0.028397	0.214676	995.82	1.5229							--	44
12707	21.0	102.51	0.429	0.028562	0.056267	998.02	1.2186							0.11768	2
22707	23.0	117.13	0.327	0.028437	0.085438	997.57	1.3829							--	2
32707	24.5	121.45	0.440	0.028562	0.113387	997.20	1.4266							--	2
42707	25.5	128.23	0.542	0.028969	0.155562	996.94	1.5012							0.00456	4
12807	21.5	116.96	0.244	0.039091	0.046515	997.91	1.3879							0.28803	2
22807	23.5	124.68	0.407	0.039657	0.084173	997.45	1.4695							--	24
32807	25.0	129.82	0.504	0.039211	0.116325	997.07	1.5224							--	4
42807	26.5	123.90	0.552	0.039271	0.143274	996.67	1.4457							--	4
52807	27.0	193.25	0.602	0.038820	0.122752	996.54	2.2511							0.01937	4
62807	27.0	143.57	0.624	0.033728	0.185090	996.54	1.6724							0.02208	4

TABLE S72 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET		OUTLET		METRE FLOW PATRN		PR-GRAD KN/M3	FLOW PATTERN
								L	L/D	L	L/D	L	L/D		
12109	19.0	103.79	0.206	0.019151	0.001942	998.44	1.2422							0.00209	3
22109	21.5	105.12	0.204	0.019212	0.003927	997.91	1.2474							0.00204	34
32109	22.5	105.89	0.206	0.019212	0.009813	997.68	1.2522							0.00198	4
42109	24.0	104.12	0.102	0.024578	0.001866	997.32	1.2251							0.00183	3
52109	25.0	106.55	0.109	0.024578	0.004061	997.07	1.2495							0.00172	4
62109	27.0	105.08	0.306	0.015173	0.008215	996.54	1.2241							0.00157	3
72109	28.0	105.49	0.305	0.015179	0.013907	996.26	1.2248							0.00162	4
82109	28.5	106.03	0.311	0.015179	0.022702	996.11	1.2290							0.00167	4
92109	29.5	106.44	0.311	0.015024	0.038850	995.82	1.2297							0.00209	4
12309	21.5	103.00	0.701	0.003296	0.001993	997.91	1.2223							-.00016	3
22309	23.0	103.28	0.703	0.003352	0.010459	997.57	1.2193							0.00005	3
32309	23.5	103.41	0.702	0.003408	0.019585	997.45	1.2189							0.00021	3
42309	24.5	103.68	0.704	0.003352	0.037006	997.20	1.2179							0.00057	3

TABLE S73   PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET		OUTLET		METRE FLOW PATRN		PR-GRAD KN/M3	FLOW PATTERN
								L	L/D	L	L/D	L	L/D		
52309	25.5	103.95	0.708	0.003352	0.050959	996.94	1.2170							0.00089	34
62309	23.0	103.13	0.531	0.007802	0.002154	997.57	1.2176							0.00073	3
72309	23.5	103.93	0.524	0.007802	0.009761	997.45	1.2250							0.00047	3
82309	24.5	104.35	0.529	0.007802	0.026108	997.20	1.2257							0.00073	4
92309	25.5	104.88	0.532	0.007742	0.047562	996.94	1.2278							0.00104	4
102309	26.5	103.38	0.459	0.009822	0.002166	996.67	1.2063							0.00073	3
112309	27.0	103.92	0.466	0.009822	0.010387	996.54	1.2106							0.00073	34
122309	27.5	104.74	0.462	0.009822	0.027726	996.40	1.2180							0.00052	4
132309	28.0	105.30	0.468	0.009822	0.050452	996.26	1.2225							0.00110	4
152309	18.0	103.39	0.405	0.011654	0.002139	998.63	1.2417							-.00021	3
162309	19.0	104.36	0.408	0.011573	0.009523	998.44	1.2490							-.00021	34
172309	20.0	105.30	0.412	0.011573	0.028394	998.23	1.2559							0.00031	4
182309	20.5	105.96	0.412	0.011613	0.048378	998.13	1.2617							0.00115	4

TABLE S74 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	L/D	OUTLET L	L/D	METRE FLOW PATRN L	L/D	PR-GRAD KN/M3	FLOW PATTERN
192309	21.5	103.65	0.347	0.013721	0.002116	997.91	1.2330							0.00042	3
202309	22.5	104.74	0.350	0.013721	0.009243	997.68	1.2387							0.00031	34
212309	23.0	105.56	0.357	0.013721	0.026864	997.57	1.2463							0.00057	4
222309	24.0	106.37	0.357	0.013686	0.048122	997.32	1.2516							0.00172	4
232309	25.0	103.51	0.298	0.015814	0.002153	997.07	1.2139							0.00052	3
242309	26.0	105.14	0.298	0.015784	0.010031	996.81	1.2288							0.00026	34
252309	27.0	105.41	0.302	0.015784	0.017711	996.54	1.2279							0.00037	4
262309	27.5	105.95	0.305	0.015784	0.029456	996.40	1.2322							0.00110	4
272309	25.5	103.79	0.238	0.017500	0.002144	996.94	1.2151							0.00037	3
282309	26.0	105.13	0.258	0.017500	0.005254	996.81	1.2287							0.00031	34
292309	27.0	105.68	0.252	0.017500	0.010947	996.54	1.2310							0.00031	4
302309	28.0	106.08	0.234	0.017500	0.015675	996.26	1.2316							0.00057	4
100810	18.5	103.09	--	0.003121	0.014263	998.53	1.2359							0.00042	3

TABLE S75 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	L/D	OUTLET L	L/D	METRE FLOW PATRN L	L/D	PR-GRAD KN/M3	FLOW PATTERN
110810	20.0	103.21	:--	0.005475	0.014093	998.23	1.2310							0.00047	3
120810	21.5	103.61	:--	0.007471	0.014329	997.91	1.2295							0.00047	34
130810	21.0	104.29	:--	0.009678	0.014273	998.02	1.2396							0.00057	34
140810	21.0	104.55	:--	0.011549	0.014220	998.02	1.2428							0.00052	4
150810	21.0	104.68	:--	0.013924	0.014199	998.02	1.2443							0.00042	4
160810	21.5	104.94	:--	0.015796	0.014172	997.91	1.2453							0.00042	4
170810	21.5	105.36	:--	0.017317	0.014116	997.91	1.2502							0.00057	4
180810	21.5	103.35	:--	0.003091	0.029882	997.91	1.2264							0.00047	3
190810	22.0	103.47	:--	0.005336	0.030601	997.80	1.2258							0.00052	34
200810	22.0	103.87	:--	0.007583	0.030822	997.80	1.2305							0.00057	4
210810	22.0	105.23	:--	0.011565	0.029329	997.80	1.2466							0.00078	4
220810	21.5	104.55	:--	0.009803	0.029559	997.91	1.2407							0.00057	4
230810	23.5	105.49	:--	0.013944	0.030006	997.45	1.2434							0.00123	4

TABLE S76 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	L/D	OUTLET L	L/D	METRE FLOW PATRN L	L/D	PR-GRAD KN/M3	FLOW PATTERN
240810	22.5	105.76	:--	0.015736	0.029879	997.68	1.2507							0.00141	4
250810	22.5	103.75	:--	0.003091	0.049367	997.68	1.2270							0.00099	34
260810	23.5	103.87	:--	0.005336	0.049641	997.45	1.2243							0.00130	4
270810	24.5	104.41	:--	0.007496	0.049667	997.20	1.2265							0.00141	4
280810	26.0	105.69	:--	0.009803	0.049426	996.81	1.2283							0.00172	4
290810	25.0	103.49	:--	0.011549	0.049187	997.07	1.2371							0.00193	4
300810	23.0	105.90	:--	0.013809	0.048784	997.57	1.2502							0.00235	4
12409	19.0	104.60	0.742	0.003489	0.106573	998.44	1.2519							0.00151	4
22409	20.0	105.00	0.627	0.003388	0.108543	998.23	1.2524							0.00251	4
32409	21.0	105.54	0.571	0.007434	0.110033	998.02	1.2546							0.00381	4
42409	22.0	106.80	0.623	0.007370	0.159449	997.80	1.2652							0.00735	4
52409	22.5	106.13	0.658	0.005309	0.160047	997.68	1.2551							0.00726	4
62409	23.5	105.33	0.736	0.003210	0.161312	997.45	1.2414							0.00590	4

TABLE S77 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET		OUTLET		METRE FLOW PATRN		PR-GRAD KN/M3	FLOW PATTERN
								L	L/D	L	L/D	L	L/D		
72409	24.5	106.13	0.766	0.003268	0.213754	997.20	1.2467							0.00715	4
82409	25.0	107.07	0.698	0.005475	0.210143	997.07	1.2556							0.00361	4
92409	25.5	108.15	0.547	0.007681	0.208308	996.94	1.2662							0.00783	4
102409	26.0	109.00	0.710	0.007620	0.238148	996.81	1.2740							0.00887	4
112409	26.0	108.03	0.732	0.005388	0.241971	996.81	1.2627							0.00736	4
122409	26.5	108.96	0.776	0.003352	0.245843	996.67	1.2481							0.00733	4
142409	18.0	107.23	0.480	0.009774	0.116362	998.63	1.2878							--	4
152409	19.0	107.36	0.471	0.011492	0.118896	998.44	1.2849							--	4
162409	20.5	108.66	0.522	0.011451	0.150295	998.13	1.2938							--	4
172409	21.5	110.00	0.533	0.013755	0.161970	997.91	1.3054							--	4
182409	23.5	107.59	0.531	0.010011	0.159387	997.45	1.2681							--	4
192409	25.0	109.48	0.513	0.009869	0.196426	997.07	1.2839							--	4
202409	25.0	110.30	0.612	0.011573	0.197674	997.07	1.2970							--	4

TABLE S78 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L		OUTLET L		METRE FLOW PATRN L		PR-GRAD KN/M3	FLOW PATTERN
								L	L/D	L	L/D	L	L/D		
212409	26.0	112.13	0.590	0.013789	0.190883	996.81	1.3106							--	4
10510	21.0	104.57	--	0.003121	0.129594	998.02	1.2430							0.00459	4
20510	22.0	105.11	--	0.003121	0.169744	997.80	1.2452							0.00546	4
30510	23.0	105.50	--	0.003091	0.193932	997.57	1.2456							0.00600	4
40510	24.0	106.46	--	0.003060	0.243233	997.32	1.2527							0.00884	4
50510	25.0	105.10	--	0.005559	0.121202	997.07	1.2325							0.00546	4
60510	26.0	105.90	--	0.005509	0.163791	996.81	1.2378							0.00742	4
70510	26.5	106.58	--	0.005526	0.194268	996.67	1.2436							0.00994	4
80510	27.0	107.98	--	0.005492	0.242753	996.54	1.2579							0.01419	6
10610	18.5	105.35	--	0.007496	0.083721	998.53	1.2630							0.00338	4
20610	19.5	106.02	--	0.007539	0.116463	998.34	1.2667							0.00644	4
30610	21.5	107.22	--	0.007539	0.162268	997.91	1.2723							0.00797	4
40610	23.0	107.78	--	0.007434	0.198501	997.57	1.2725							0.00906	4

TABLE S79 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING INLET L	L/D	LENGTH,L OUTLET L	L/D	METRE FLOW PATRN L	L/D	PR-GRAD KN/M3	FLOW PATTERN
50610	23.5	109.01	:--	0.007718	0.235447	997.45	1.2849							0.01201	4
60610	24.0	106.69	:--	0.009822	0.132766	997.32	1.2554							0.00502	4
70610	25.5	107.90	:--	0.009774	0.163296	996.94	1.2632							0.00731	4
80610	26.0	108.71	:--	0.009707	0.187837	996.81	1.2706							0.00742	4
90610	26.5	109.98	:--	0.009673	0.227119	996.67	1.2833							0.00994	4
110610	18.0	107.20	:--	0.011492	0.113177	998.63	1.2874							-.00109	4
120610	20.0	109.08	:--	0.011532	0.163172	998.23	1.3011							0.00393	4
130610	21.0	109.78	:--	0.011451	0.189201	998.02	1.3049							0.00939	4
140610	22.0	111.92	:--	0.011742	0.230318	997.80	1.3258							0.01430	44
150610	23.5	111.99	:--	0.013755	0.195478	997.45	1.3199							0.01507	44
160610	24.0	112.88	:--	0.013789	0.221874	997.32	1.3282							0.01430	44
170610	24.5	114.78	:--	0.015932	0.220058	997.20	1.3483							0.01245	44
180610	25.0	113.30	:--	0.015990	0.193367	997.07	1.3287							0.01223	44

TABLE S80 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET		OUTLET		METRE FLOW PATRN		PR-GRAD KN/M3	FLOW PATTERN
								L	L/D	L	L/D	L	L/D		
10710	18.5	114.77	:--	0.018964	0.168782	998.53	1.3760							0.01015	44
20710	21.0	116.04	:--	0.018964	0.198110	998.02	1.3793							0.01146	44
30710	22.0	117.67	:--	0.018964	0.219637	997.80	1.3940							0.01179	44
40710	23.0	119.63	:--	0.024329	0.169682	997.57	1.4124							0.01603	44
50710	24.0	121.94	:--	0.024291	0.192063	997.32	1.4348							0.01758	44
60710	24.5	124.37	:--	0.024000	0.210629	997.20	1.4610							0.01856	44
80710	18.0	122.97	:--	0.028969	0.157124	998.63	1.4768							0.01004	44
90710	19.0	125.15	:--	0.028807	0.172728	998.44	1.4978							0.01163	44
100710	20.0	128.34	:--	0.029011	0.186196	998.23	1.5308							0.01256	44
110710	23.0	126.99	:--	0.033063	0.144221	997.57	1.4993							0.01441	44
120710	24.0	130.20	:--	0.032956	0.163474	997.32	1.5320							0.01507	44
130710	25.0	132.32	:--	0.032813	0.174651	997.07	1.5518							0.01583	44
10810	18.0	131.51	:--	0.039598	0.120361	998.63	1.5794							0.01070	44

TABLE S81 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET		OUTLET		METRE FLOW PATRN		PR-GRAD KN/M3	FLOW PATTERN
								L	L/D	L	L/D	L	L/D		
20810	19.0	134.18	--	0.039330	0.143776	998.44	1.6059							0.01365	44
30810	21.0	137.91	--	0.039271	0.157037	998.02	1.6394							0.01397	44
40810	22.5	139.60	--	0.046253	0.120740	997.68	1.6510							0.01433	44
50810	24.0	143.01	--	0.046150	0.134793	997.32	1.6828							0.01507	44
60810	25.0	146.24	--	0.046200	0.147012	997.07	1.7150							0.01649	44
70810	26.0	147.14	--	0.056001	0.096342	996.81	1.7198							0.01135	44
80810	26.5	149.25	--	0.055831	0.108194	996.67	1.7415							0.01283	44

TABLE S82 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	L/D	OUTLET L	L/D	METRE FLOW PATRN L	L/D	PR-GRAD KN/M3	FLOW PATTERN
12109	19.0	103.79	0.206	0.019151	0.001942	998.44	1.2422							0.02350	3
22109	21.5	105.12	0.204	0.019212	0.003927	997.91	1.2474							0.02379	34
32109	22.5	105.89	0.206	0.019212	0.009813	997.68	1.2522							0.02507	4
42109	24.0	104.12	0.102	0.024578	0.001866	997.32	1.2251							0.02849	3
52109	25.0	106.53	0.109	0.024578	0.004061	997.07	1.2495							0.02963	4
62109	27.0	105.08	0.306	0.015173	0.008215	996.54	1.2241							0.02165	3
72109	28.0	105.49	0.305	0.015179	0.013907	996.26	1.2248							0.02137	4
82109	28.5	106.03	0.311	0.015179	0.022702	996.11	1.2290							0.02123	4
92109	29.5	106.44	0.311	0.015024	0.038850	995.82	1.2297							0.02137	4
12309	21.5	103.00	0.701	0.003296	0.001993	997.91	1.2223							0.01040	3
22309*	23.0	103.28	0.703	0.003352	0.010459	997.57	1.2193							0.01040	3
32309	23.5	103.41	0.702	0.003408	0.019585	997.45	1.2189							0.01011	3
42309	24.5	103.68	0.704	0.003352	0.037006	997.20	1.2179							0.01025	3

TABLE S83 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L METRE						PR-GRAD KN/M3	FLOW PATTERN
								INLET L	INLET L/D	OUTLET L	OUTLET L/D	FLOW PATRN L	FLOW PATRN L/D		
52309	25.5	103.95	0.708	0.003352	0.050959	996.94	1.2170							0.01040	34
62309	23.0	103.13	0.531	0.007802	0.002154	997.57	1.2176							0.01524	3
72309	23.5	103.93	0.524	0.007802	0.009761	997.45	1.2250							0.01496	3
82309	24.5	104.35	0.529	0.007802	0.026108	997.20	1.2257							0.01467	4
92309	25.5	104.88	0.532	0.007742	0.047562	996.94	1.2278							0.01496	4
102309	26.5	103.38	0.459	0.009822	0.002166	996.67	1.2063							0.01367	3
112309	27.0	103.92	0.466	0.009822	0.010387	996.54	1.2106							0.01367	34
122309	27.5	104.74	0.462	0.009822	0.027726	996.40	1.2180							0.01652	4
132309	28.0	105.30	0.468	0.009822	0.050452	996.26	1.2225							0.01595	4
152309	18.0	103.39	0.405	0.011654	0.002139	998.63	1.2417							0.01738	3
162309	19.0	104.36	0.408	0.011573	0.009523	998.46	1.2490							0.01724	34
172309	20.0	105.30	0.412	0.011573	0.028394	998.23	1.2359							0.01724	4
182309	20.5	105.96	0.412	0.011613	0.048378	998.13	1.2617							0.01695	4

TABLE S84 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	INLET L/D	OUTLET L	OUTLET L/D	METRE FLOW PATRN L	METRE FLOW PATRN L/D	PR-GRAD KN/M3	FLOW PATTERN
192309	21.5	103.65	0.347	0.013721	0.002116	997.91	1.2300							0.01980	3
202309	22.5	104.74	0.350	0.013721	0.009243	997.68	1.2387							0.01923	34
212309	23.0	105.56	0.357	0.013721	0.026864	997.57	1.2463							0.0189[illegible]	4
222309	24.0	106.37	0.357	0.013686	0.048122	997.32	1.2516							0.01823	4
232309	25.0	103.51	0.298	0.015814	0.002153	997.07	1.2139							0.02123	3
242309	26.0	105.14	0.298	0.015784	0.010031	996.81	1.2288							0.02080	34
252309	27.0	105.41	0.302	0.015784	0.017711	996.56	1.2279							0.02037	4
262309	27.5	105.95	0.305	0.015784	0.029456	996.40	1.2322							0.01994	4
272309	25.5	103.79	0.258	0.017500	0.002144	996.94	1.2151							0.02203	3
282309	25.0	105.13	0.258	0.017500	0.005254	996.81	1.2287							0.02251	34
292309	27.0	105.68	0.252	0.017500	0.010947	996.54	1.2310							0.02165	4
302309	28.0	106.08	0.254	0.017500	0.015675	996.26	1.2316							0.02255	4
100810	18.5	103.09	--	0.003121	0.014263	998.53	1.2359							0.01054	3

TABLE S 85 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET		OUTLET		METRE FLOW PATRN		PR-GRAD KN/M3	FLOW PATTERN
								L	L/D	L	L/D	L	L/D		
110810	20.0	103.21	:--	0.005475	0.014093	998.23	1.2310							0.01453	3
120810	21.5	103.61	:--	0.007471	0.014329	997.91	1.2295							0.01681	34
130810	21.0	104.29	:--	0.009678	0.014273	998.02	1.2396							0.01793	34
140810	21.0	104.55	:--	0.011549	0.014220	998.02	1.2428							0.01994	4
150810	21.0	104.68	:--	0.013924	0.014199	998.02	1.2443							0.02137	4
160810	21.5	104.94	:--	0.015796	0.014172	997.91	1.2453							0.02237	4
170810	21.5	105.36	:--	0.017317	0.014116	997.91	1.2502							0.02265	4
180810	21.5	103.35	:--	0.003091	0.029882	997.91	1.2264							0.01182	3
190810	22.0	103.47	:--	0.005336	0.030601	997.80	1.2258							0.01481	34
200810	22.0	103.87	:--	0.007583	0.030822	997.80	1.2305							0.01667	4
210810	22.0	105.23	:--	0.011565	0.029329	997.80	1.2466							0.01965	4
220810	21.5	104.55	:--	0.009803	0.029559	997.91	1.2407							0.01809	4
230810	23.5	105.49	:--	0.013944	0.030006	997.45	1.2434							0.02137	4

TABLE S86 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	L/D	OUTLET L	L/D	METRE FLOW PATRN L	L/D	PR-GRAD KN/M3	FLOW PATTERN
240810	22.5	105.76	--	0.015736	0.029879	997.68	1.2507							0.02222	4
230810	22.5	103.73	--	0.003091	0.049367	997.68	1.2270							0.01311	34
260810	23.5	103.87	--	0.005336	0.049641	997.45	1.2243							0.01496	4
270810	24.5	104.41	--	0.007496	0.049667	997.20	1.2265							0.01709	4
280810	26.0	105.09	--	0.009803	0.049426	996.81	1.2283							0.01852	4
290810	25.0	105.49	--	0.011549	0.049187	997.07	1.2371							0.01965	4
300810	23.0	105.90	--	0.013809	0.048784	997.57	1.2502							0.02108	4
12409	19.0	104.60	0.742	0.003489	0.106573	998.44	1.2519							0.01083	4
22409	20.0	105.00	0.627	0.005388	0.108543	998.23	1.2524							0.01225	4
32409	21.0	105.54	0.571	0.007434	0.110033	998.02	1.2546							0.01339	4
42409	22.0	106.80	0.623	0.007370	0.159449	997.80	1.2652							0.01510	4
52409	22.5	106.13	0.658	0.005509	0.160047	997.68	1.2551							0.01083	4
62409	23.5	105.33	0.736	0.003210	0.161312	997.45	1.2414							0.00855	4

TABLE S87 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	L/D	OUTLET L	L/D	METRE FLOW PATRN L	L/D	PR-GRAD KN/M3	FLOW PATTERN
72409	24.5	106.13	0.766	0.003268	0.213754	997.20	1.2467							0.01125	4
82409	25.0	107.07	0.698	0.005475	0.210143	997.07	1.2556							0.01111	4
92409	25.5	108.15	0.647	0.007681	0.208308	996.94	1.2662							0.01581	4
102409	26.0	109.00	0.710	0.007620	0.238148	996.81	1.2740							0.00355	4
112409	26.0	108.03	0.732	0.005388	0.241971	996.91	1.2627							0.01156	4
122409	26.5	106.96	0.776	0.003352	0.245843	996.67	1.2481							0.00499	4
142409	18.0	107.23	0.480	0.009774	0.116362	998.63	1.2878							0.01823	4
152409	19.0	107.36	0.471	0.011492	0.118896	998.44	1.2849							0.02066	4
162409	20.5	108.66	0.522	0.011451	0.150295	998.13	1.2938							0.02635	4
172409	21.5	110.00	0.553	0.013755	0.161970	997.91	1.3054							0.03105	4
182409	23.5	107.59	0.551	0.010011	0.159387	997.45	1.2681							0.02479	4
192409	25.0	109.48	0.613	0.009869	0.196426	997.07	1.2839							0.02293	4
202409	25.0	110.60	0.612	0.011573	0.197674	997.07	1.2970							0.01182	4

TABLE S88 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET L	L/D	OUTLET L	L/D	METRE FLOW PATRN L	L/D	PR-GRAD KN/M3	FLOW PATTERN
212409	26.0	112.13	0.590	0.013789	0.190883	996.81	1.3106							0.01581	4
10510	21.0	104.57	--	0.003121	0.129594	998.02	1.2430							0.01211	4
20510	22.0	105.11	--	0.003121	0.169744	997.80	1.2452							0.01325	4
30510	23.0	105.50	--	0.003091	0.193932	997.57	1.2456							0.01681	4
40510	24.0	106.46	--	0.003060	0.243233	997.32	1.2527							0.01054	4
50510	25.0	105.10	--	0.005559	0.121202	997.07	1.2325							0.01593	4
60510	26.0	105.90	--	0.005509	0.163791	996.81	1.2378							0.01823	4
70510	26.5	106.58	--	0.005526	0.194268	996.67	1.2436							0.01909	4
80510	27.0	107.98	--	0.005492	0.242753	996.54	1.2579							0.01581	4
10610	18.5	105.35	--	0.007496	0.083721	998.53	1.2630							0.01823	4
20610	19.5	106.02	--	0.007559	0.116463	998.34	1.2667							0.01781	4
30610	21.5	107.22	--	0.007559	0.162268	997.91	1.2723							0.02450	4
40610	23.0	107.78	--	0.007434	0.198501	997.57	1.2725							0.02279	4

TABLE S89 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VCID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L METRES						PR-GRAD KN/M3	FLOW PATTERN
								INLET		OUTLET		FLOW PATRN			
								L	L/D	L	L/D	L	L/D		
50610	23.5	109.01	:--	0.007718	0.235447	997.45	1.2849							0.01766	4
60610	24.0	106.69	:--	0.009822	0.132766	997.32	1.2554							0.02165	4
70610	25.5	107.90	:--	0.009774	0.163296	996.94	1.2632							0.02678	4
80610	26.0	108.71	:--	0.009707	0.187837	996.81	1.2706							0.02521	4
90610	26.5	109.98	:--	0.009678	0.227119	996.67	1.2833							0.00655	4
110610	18.0	107.20	:--	0.011492	0.113177	998.63	1.2874							0.02536	4
120610	20.0	109.08	:--	0.011532	0.163172	998.23	1.3011							0.02992	4
130610	21.0	109.78	:--	0.011451	0.189201	998.02	1.3049							0.02707	4
140610	22.0	111.92	:--	0.011742	0.230318	997.80	1.3258							-.01240	44
150610	23.5	111.99	:--	0.013755	0.195478	997.45	1.3199							0.00953	44
160610	24.0	112.88	:--	0.013789	0.221874	997.32	1.3282							-.01795	44
170610	24.5	114.78	:--	0.015932	0.220058	997.20	1.3483							-.01866	44
180610	25.0	113.30	:--	0.015990	0.193367	997.07	1.3237							-.02155	44

TABLE S90 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING LENGTH,L INLET		OUTLET		METRE FLOW PATRN		PR-GRAD KN/M3	FLOW PATTERN
								L	L/D	L	L/D	L	L/D		
10710	18.5	114.77	--	0.018964	0.168782	998.53	1.3760							-.00570	44
20710	21.0	116.04	--	0.018964	0.198110	998.02	1.3793							-.01781	44
30710	22.0	117.67	--	0.018964	0.219637	997.80	1.3940							-.01824	44
40710	23.0	119.63	--	0.024329	0.169582	997.57	1.4124							-.01980	44
50710	24.0	121.94	--	0.024291	0.192063	997.32	1.4348							-.01923	44
60710	24.5	124.37	--	0.024000	0.210629	997.20	1.4610							-.01795	44
80710	18.0	122.97	--	0.028969	0.157124	998.53	1.4768							-.02536	44
90710	19.0	125.15	--	0.028807	0.172728	998.46	1.4978							-.02265	44
100710	20.0	128.34	--	0.029011	0.186196	998.23	1.5308							-.02037	44
110710	23.0	126.99	--	0.033063	0.144221	997.57	1.4993							-.02593	44
120710	24.0	130.20	--	0.032956	0.163474	997.32	1.5320							-.02393	44
130710	25.0	132.32	--	0.032813	0.174551	997.07	1.5518							-.02208	44
10810	18.0	131.51	--	0.039598	0.120361	998.63	1.5794							-.02707	44

TABLE S91 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

TEST RUN NO	TEMP C	P MEAN KN/M2	VOID FRCTN	WATER FLOW RATE M3/SEC	AIR FLOW RATE M3/SEC	DENSITY WATER KG/M3	DENSITY AIR KG/M3	SETTLING INLET		LENGTH,L OUTLET		METRE FLOW PATRN		PR-GRAD KN/M3	FLOW PATTERN
								L	L/D	L	L/D	L	L/D		
20810	19.0	134.18	--	0.039330	0.143776	998.44	1.6059							-.02834	44
30810	21.0	137.91	--	0.039271	0.157037	998.02	1.6394							-.02148	44
40810	22.5	139.60	--	0.046253	0.120740	997.68	1.6510							-.02609	44
50810	24.0	143.01	--	0.046150	0.134793	997.32	1.6828							-.02461	44
60810	25.0	146.24	--	0.045200	0.147012	997.07	1.7150							-.02650	44
70810	26.0	147.14	--	0.055001	0.096342	996.81	1.7198							-.02854	44
80810	26.5	149.25	--	0.055831	0.108194	996.67	1.7415							-.02764	44

TABLE S92 PRESSURE DROP,SETTLING LENGTH AND OTHER DATA DERIVED FROM EXPERIMENTAL READINGS

APPENDIX T FRICTION PRESSURE DROP CORRELATIONS

APPENDIX T FRICTION PRESSURE DROP CORRELATIONS

Details of the friction pressure drop correlations used in comparison with the experimental data are given here.

T.1 HOMOGENEOUS FLOW MODEL

$$\left(\frac{dP}{dZ}\right) = \frac{\lambda_H G^2}{2D} \quad \frac{x}{\rho_g} + \frac{(1-x)}{\rho_f} \tag{T1}$$

where λ_H obtained from the friction characteristic corresponding to $Re = \frac{GD}{\mu_H}$ (T2)

$$\text{with } \mu_H = \frac{Q_g \mu_g + Q_f \mu_f}{Q_f + Q_g} = \beta \mu_g + (1-\beta)\mu_f \tag{T3}$$

$$\left(\frac{dP}{dZ}\right)_{fo} = \frac{\lambda_{fo} G^2}{2D \ \rho_f} \tag{T4}$$

where λ_{fo} obtained from the friction characteristic corresponding to $Re = \frac{GD}{\mu_f}$ (T5)

$$\text{Hence } \phi^2_{fo} = \frac{\lambda_H}{\lambda_{fo}} \left[\frac{x \ \rho_f}{\rho_g} + (1 - x) \right] \tag{T6}$$

$$\text{Also } \left(\frac{dP}{dZ}\right)_{go} = \frac{\lambda_{go} G^2}{2D \ \rho_g} \tag{T7}$$

where λ_{go} obtained from the friction characteristic corresponding to $Re = \frac{GD}{g}$ (T8)

$$\text{Hence } \phi^2_{go} = \frac{\lambda_H}{\lambda_{go}} \left[x + (1-x) \frac{\rho_g}{\rho_f} \right] \tag{T9}$$

T.2 LOCKHART-MARTINELLI

Values of ϕ_f^2 and ϕ_g^2 are given in Fig. T.1 and Table T-1 to a base of parameter X where

$$X = \frac{(dP/dZ)_f}{(dP/dZ)_g} \tag{T10}$$

and

$$\left(\frac{dP}{dZ}\right)_f = \frac{\lambda_f (1 - x)^2 G^2}{2D\ \rho_f} \tag{T11}$$

with λ_f obtained from the friction characteristic corresponding to

$$Re = \frac{(1-x)GD}{\mu_f} \tag{T12}$$

$$\left(\frac{dP}{dZ}\right)_g = \frac{\lambda_g\ x^2\ G^2}{2D\ \rho_g} \tag{T13}$$

with λ_g obtained from the friction characteristics corresponding to

$$Re = \frac{x\ G\ D}{\mu_g} \tag{T14}$$

Now

$$\phi_{f_o}^2 = \phi_f^2 (1 - x)^2\ \frac{\lambda_f}{\lambda_{f_o}} \tag{T15}$$

and

$$\phi_{g_o}^2 = \phi_g^2\ x^2\ \frac{\lambda_g}{\lambda_{g_o}} \tag{T16}$$

T.3 CHENOWETH-MARTIN

Here the values of $\phi_{f_o}^2$ are obtained from the experimental data shown in Table T-2, knowning the liquid volume fraction

$$1 - \beta = \frac{Q_f}{Q_f + Q_g} \tag{T17}$$

VV VISCOUS VISCOUS

Vt VISCOUS TURBULENT

tV TURBULENT VISCOUS

tt TURBULENT TURBULENT

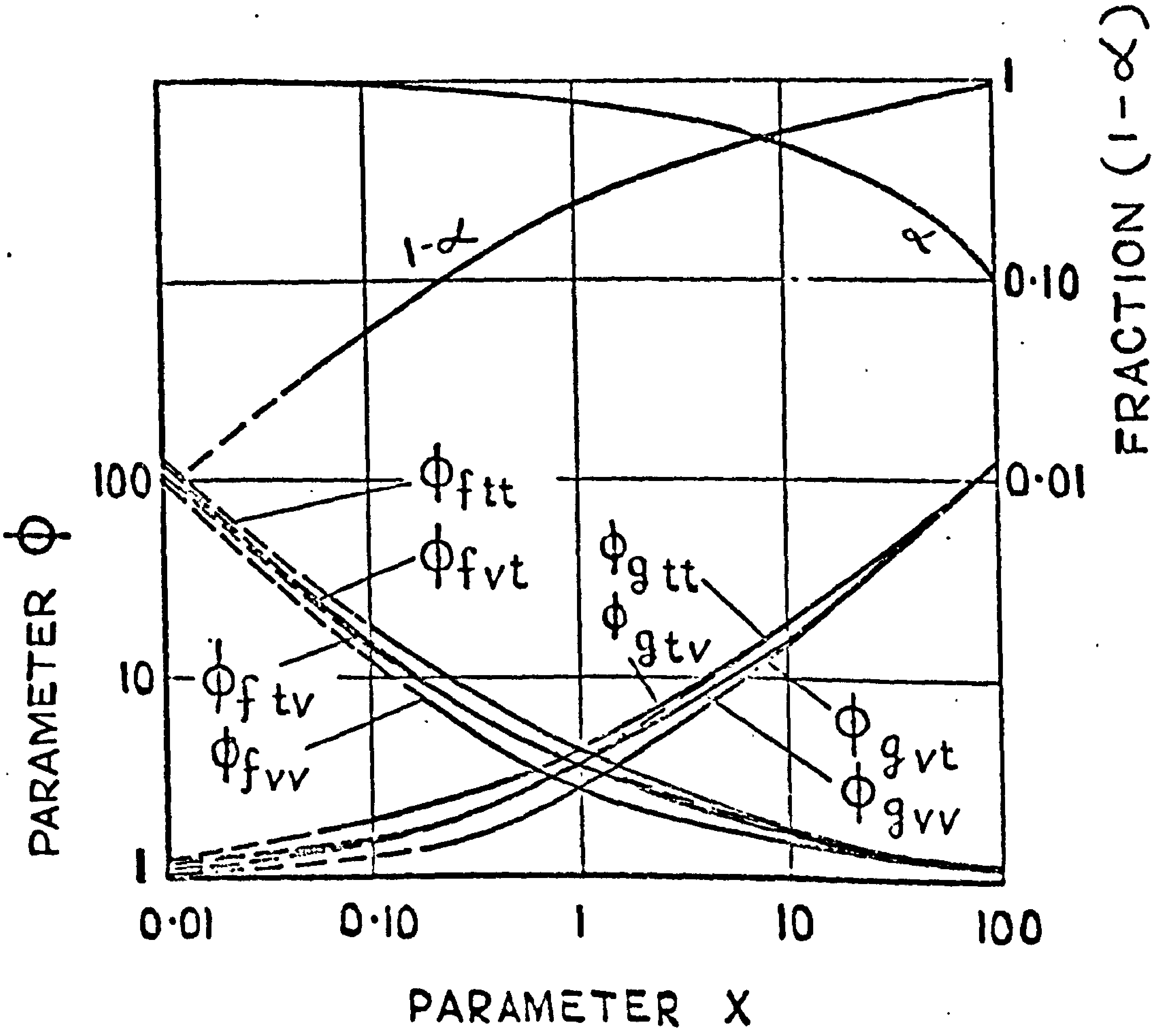


FIG. T1

RELATIONSHIPS BETWEEN ϕ, α AND X FOR ALL FLOW MECHANISMS (LOCKHART & MARTINELLI).

	All Mechanisms		Turbulent-Turbulent		Viscous-Turbulent		Turbulent-Viscous		Viscous-Viscous	
x	$1-\alpha$	α	ϕ_f	ϕ_g	ϕ_f	ϕ_g	ϕ_f	ϕ_g	ϕ_f	ϕ_g
0.01	-	-	128	1.28	120	1.20	112	1.12	105	1.05
0.02	-	-	68.4	1.37	64	1.28	58	1.16	53.5	1.07
0.04	-	-	38.5	1.54	34	1.36	31	1.24	28.0	1.12
0.07	0.04	0.96	24.4	1.71	20.7	1.45	19.3	1.35	17.0	1.19
0.1	0.05	0.95	18.5	1.85	15.2	1.52	14.5	1.45	12.4	1.24
0.2	0.09	0.91	11.2	2.23	8.90	1.78	8.70	1.74	7.00	1.40
0.4	0.14	0.86	7.05	2.83	5.62	2.25	5.50	2.20	4.25	1.70
0.7	0.19	0.81	5.04	2.53	4.07	2.85	4.07	2.85	3.08	2.16
1.0	0.23	0.77	4.20	3.48	3.48	3.48	3.48	3.48	2.61	2.61
2.0	0.31	0.69	3.10	6.20	2.62	5.25	2.62	5.24	2.06	4.12
4.0	0.40	0.60	2.38	9.50	2.05	8.20	2.15	8.60	1.76	7.00
7.0	0.48	0.52	1.96	13.7	1.73	12.1	1.83	12.8	1.60	11.2
10	0.53	0.47	1.75	17.5	1.59	15.9	1.66	16.6	1.50	15.0
20	0.66	0.34	1.48	29.5	1.40	28.0	1.44	28.8	1.36	27.3
40	0.76	0.24	1.29	51.5	1.25	50	1.25	50	1.25	50
70	0.84	0.16	1.17	82	1.17	82	1.17	82	1.17	82
100	0.90	0.10	1.11	111	1.11	111	1.11	111	1.11	111

TABLE T-1 COORDINATES OF α AND ϕ VERSUS THE PARAMETER X (LOCKHART-MARTINELLI)

Liquid Volume Fraction (1 -)	Values of Z				
	50	100	200	500	1000
0	50	100	200	500	1000
0.00001	56.5	113	225	565	1125
0.00002	58.5	117	235	585	1175
0.00004	62.0	124	248	620	1230
0.00007	63.5	127	254	635	1200
0.00001	64.5	129	258	645	1150
0.0002	66.0	132	255	580	950
0.0004	67.5	129	249	470	680
0.0007	65.0	121	219	385	470
0.001	62.0	115	199	325	370
0.002	58.0	99	153	215	215
0.004	50.0	82	105	120	120
0.007	41.0	60	71.0	72.5	72.5
0.01	34.5	48	53.0	53.0	53.0
0.02	24.0	29.2	29.2	29.2	29.2
0.04	15.0	16.1	16.1	16.1	16.1
0.07	9.90	9.9	9.90	9.90	9.90
0.1	7.40	7.4	7.40	7.40	7.40
0.2	4.05	4.05	4.05	4.05	4.05
0.4	2.22	2.22	2.22	2.22	2.22
0.7	1.38	1.38	1.38	1.38	1.38
1.0	1.0	1.0	1.0	1.0	1.0

TABLE T-2 $\phi_{f_o}^2$ VALUES FROM CHENOWETH-MARTIN and a parameter Z, where

$$Z = \frac{(dP/dZ)_{go}}{(dP/dZ)_{fo}}$$, see equations (T4) and (T7).

T.4 BAROCZY

Baroczy gives $\phi^2_{f_o}$ = function (property index, mass dryness fraction, mass velocity), where

$$\text{property index} = \left(\frac{\mu_f}{\mu_g}\right)^{0.2} \left(\frac{\rho_g}{\rho_f}\right) \qquad \text{(T18)}$$

the method of evaluating $\phi^2_{f_o}$ is as follows,

Step 1. Obtain values of $\phi^2_{f_o}$ from Table T-3 corresponding to particular values of property index and mass dryness fraction. These values correspond to a mass velocity of 1356 kg/sm^2 (10^6 lb/hr ft^2).

Step 2. Correct values obtained from Table T-3 using the 'multiplier ratio', obtained from Fig. T.2 or T.3 which depends on the actual mass velocity being considered. The mass velocity correction factors can be greater or less than 1 and are essentially empirical. Hence it is possible (with factors $<$ 1) at low mass dryness fractions to obtain values of $\phi^2_{f_o} < 1$.

T.5 CHISHOLM

In this correlation

$$\phi^2_{f_o} = 1 + (\Gamma^2 - 1)\left[B(x)^{\frac{m}{2}}(1-x)^{\frac{m}{2}} + (x)^m\right] \qquad \text{(T19)}$$

Property Index $(\frac{\mu_f}{\mu_g})^{\cdot 2}(\frac{\rho_g}{\rho_f})$	Mass Dryness Fraction x															
	0	.001	.005	.01	.02	.035	.05	.075	.10	.15	.20	.30	.40	.60	.80	1.0
0.0001	1	2.20	5.80	9.20	16.0	26.5	47.0	99.0	163	376	630	1300	2050	4300	6600	10000
0.001	1	2.15	5.60	8.80	14.8	22.8	34.2	48.2	70	108	148	240	330	538	760	1000
0.004	1	2.08	4.90	7.80	11.9	16.3	22.8	29.0	36.0	49.5	63	86.0	110	155	203	250
0.01	1	1.59	3.30	4.80	7.0	9.60	12.4	16.0	20.0	27.0	33.5	43.5	53.0	69.0	85.0	100
0.03	1	1.12	1.55	1.81	2.57	3.45	4.7	6.10	7.90	11.0	13.2	17.3	21.2	26.0	30.0	33.3
0.10	1	1.04	1.12	1.22	1.48	1.78	2.05	2.50	2.80	3.60	4.20	5.50	6.50	8.0	9.10	10
0.30	1.	1.01	1.02	1.06	1.13	1.26	1.36	1.50	1.59	1.77	1.93	2.25	2.48	2.86	3.20	3.33
1.0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

TABLE T-3 $\phi^2_{f_o}$ VALUES FROM BAROCZY, G = 1356 kg/sm^2

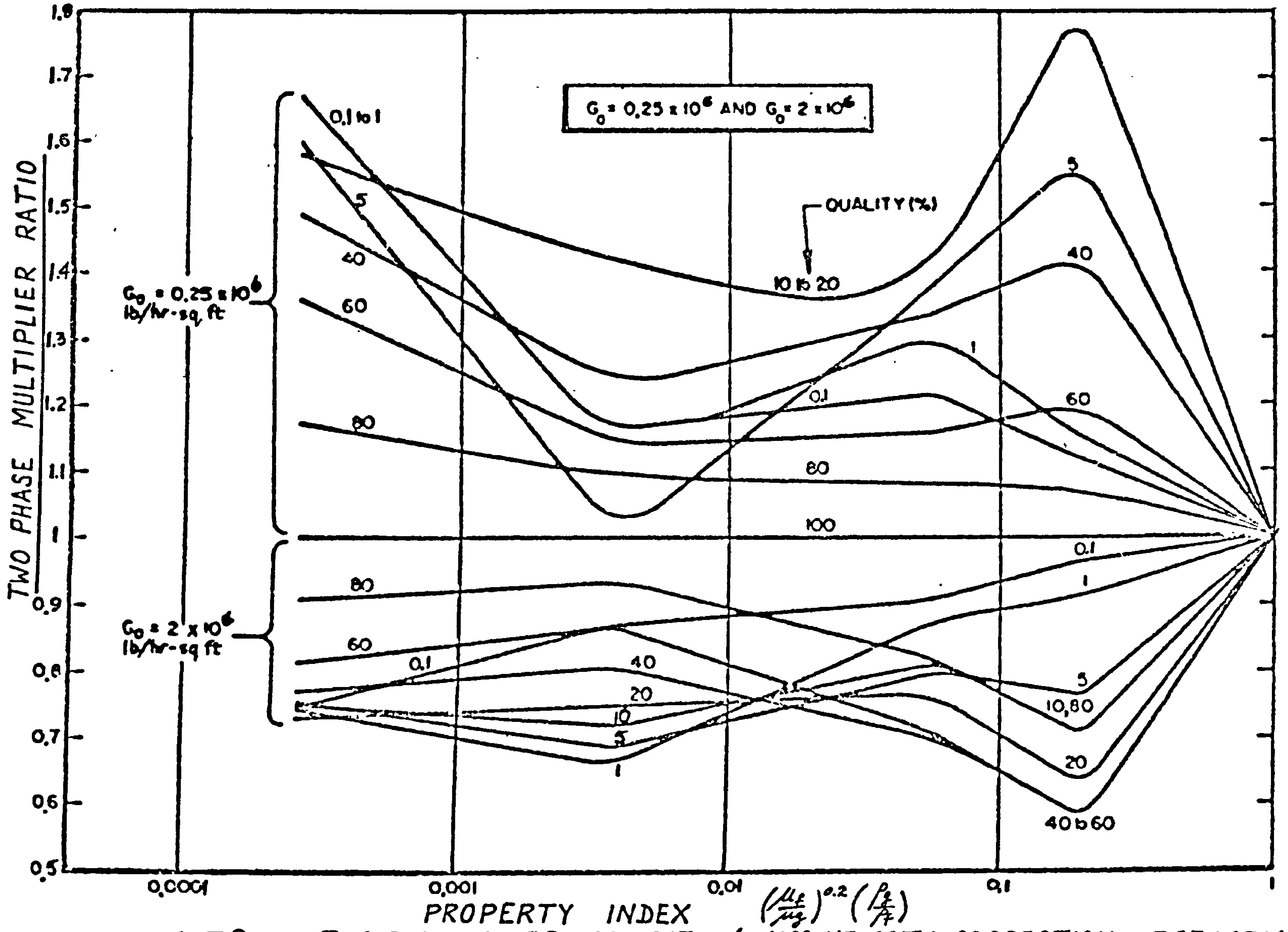


FIG T2 TWO PHASE MULTIPLIER RATIO (MASS VELOCITY CORRECTION BAROCZY)

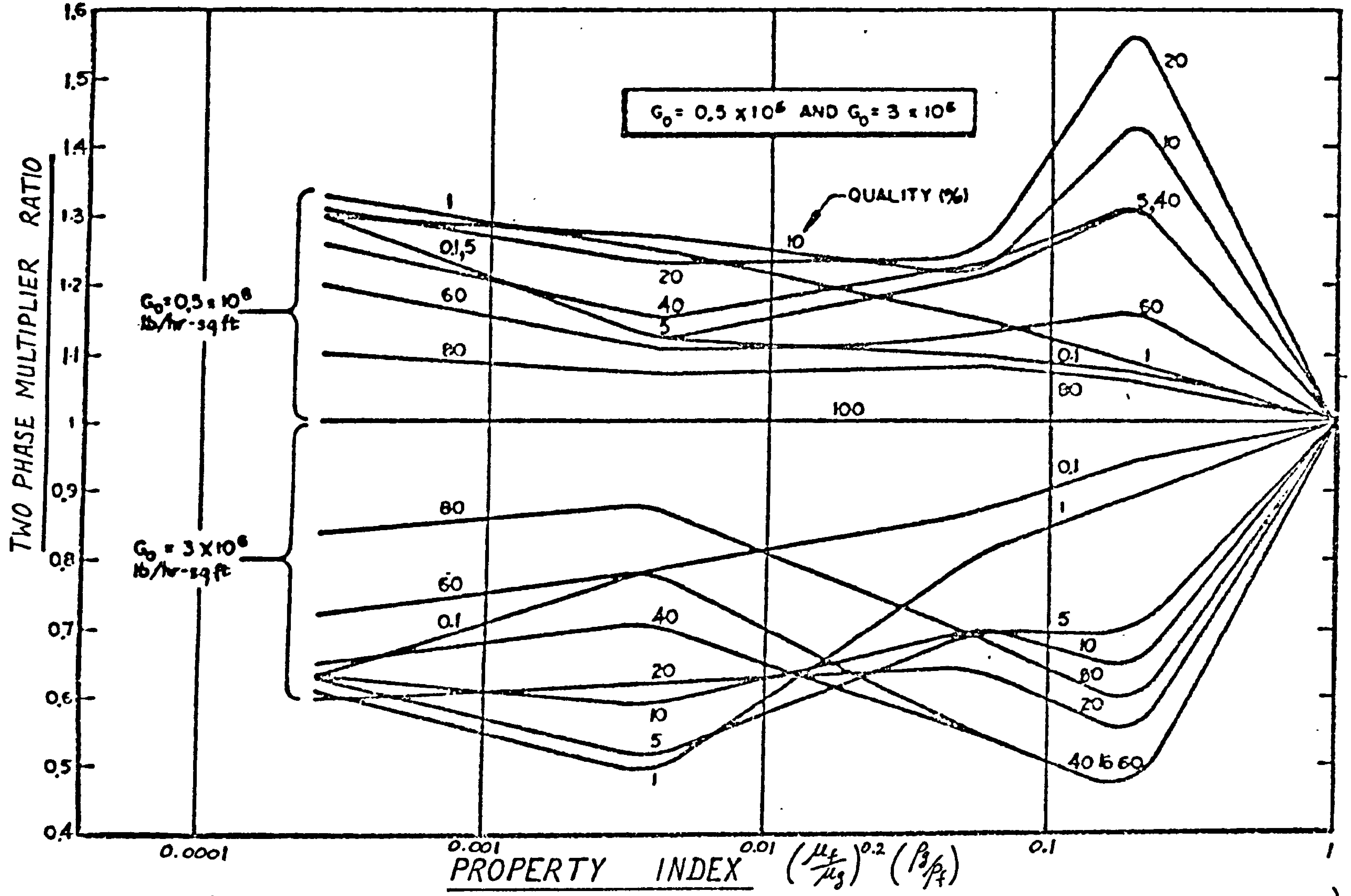


FIG T 3 TWO PHASE MULTIPLIER RATIO (MASS VELOCITY CORRECTION BAROCZY) where $\Gamma^2 = \frac{(dP/dZ)_{go}}{(dP/dZ)_{fo}}$, see equations (T4) and (T7) and $m = 2-n$, where 'n' is obtained from the friction relationship $\lambda = k\,Re^{-n}$. Values of B for smooth tubes are given in Table T-4.

T.6 DUKLER CASE II

Here
$$\left(\frac{dP}{dZ}\right) = \frac{\lambda_2 G^2}{2D\rho_H}\psi \qquad \text{(T20)}$$

where
$$\rho_H = \beta\rho_g + (1-\beta)\rho_f \qquad \text{(T21)}$$

$$\lambda_2 = \lambda_1\left[1 + \frac{R}{1.281-0.478R+0.444R^2-0.094R^3+0.00843R^4}\right] \qquad \text{(T22)}$$

where $R = -\ln(1-\beta)$

$$\psi = \frac{\rho_f}{\rho_H}\frac{(1-\beta)^2}{1-\alpha} + \frac{\rho_g}{\rho_H}\frac{\beta^2}{\alpha} \qquad \text{(T23)}$$

In equation (T22), λ_1 is evaluated from the friction characteristic corresponding to $Re = \frac{GD\psi}{\mu_H}$ (T24) and μ_H is defined as in equation (T3).

Hence
$$\phi^2_{f_o} = \frac{(dP/dZ)}{(dP/dZ)_{f_o}} \qquad \text{(T25)}$$

according to equations (T20) and (T4).

		G kg/sm^2	B
		500	4.8
9.5		500 GL1900	2400/G
		1900	$55/G^{.5}$
9.5	28	600	$520/(\quad G^{.5})$
		600	21/
28			$15000/(\quad ^{2} G^{.5})$

TABLE T-4 VALUES OF COEFFICIENT B FROM CHISHOLM

APPENDIX U SAMPLE CALCULATION OF THE TWO PHASE FRICTION MULTIPLIERS

APPENDIX U SAMPLE CALCULATION OF THE TWO PHASE FRICTION MULTIPLIERS

Phase 1, Specimen Test Run No. 100109

Air flowrate = 0.27856 m^3/s

Air density = 1.300 Kg/m^3

Water flowrate = 0.0067 m^3/s

Water density = 996.67 Kg/m^3

Water temperature = 26.5 ^oC

Pressure gradient = 0.2284 KN/m^3

Diameter = 0.127 m

CALCULATIONS

Water viscosity $\mu_f = 860.18 \times 10^{-6}$ NS/m^2 (Appendix N)

Air viscosity $\mu_g = 1.8477 \times 10^{-5}$ Ns/m^2 (Appendix N)

Mass flow of air, $M_g = \rho_g\ Q_g = 0.27856 \times 1.3$

$= 0.3621$ Kg/s

Mass flow of water, $M_f = \rho_f\ Q_f = 0.0067 \times 996.67$

$= 6.6777$ Kg/s

$$\text{Quality} = \frac{M_g}{M_g + M_f} = \frac{0.3621}{7.0398} = 0.051436$$

$$\text{Total mass velocity, } G = \frac{M_{tot}}{\frac{\pi}{4}\ D^2} = \frac{7.0398}{0.012668}$$

$= 555.728$ Kg/sm^2

$G \times D = 555.728 \times 0.127 = 70.578$ Kg/sm.

(i) Experimental

$$\left(\frac{\Delta P}{\Delta Z}\right)_{f_o} = \frac{\lambda_{f_o}}{2D} \frac{G^2}{\rho_f}$$

$$Re_f = \frac{GD}{\mu_f} = \frac{70.578}{860.18 \times 10^{-6}} = 82050.25$$

From single phase tests and for Re < 100,000

$$\lambda_{f_o} = 0.017781$$

$$\left(\frac{\Delta P}{\Delta Z}\right)_{f_o} = \frac{0.017781 \times (555.728)^2}{2 \times 0.127 \times 996.674} = 21.69 \ N/m^3$$

$$\therefore \phi^2_{f_{o_{Exp}}} = \frac{(\Delta P/\Delta Z)_{Exp.}}{(\Delta P/\Delta Z)_{f_o}} = \frac{228.4}{21.69} = \underline{10.53}$$

By computer, $\phi^2_{f_{o_{Exp.}}} = \underline{10.505}$

Also

$$\left(\frac{\Delta P}{\Delta Z}\right)_{g_o} = \frac{\lambda_{g_o}}{2D} \frac{G^2}{\rho_g}$$

$$Re_g = \frac{GD}{\mu_g} = \frac{70.578}{1.8477 \times 10^{-5}} = 3,819,775.4$$

From single phase tests for Re > 100,000

$${}_{g_o} = 0.2122 \ Re_g^{-0.2219} = 0.007348$$

$$\left(\frac{\Delta P}{\Delta Z}\right)_{g_o} = \frac{0.007348 \times (555.728)^2}{2 \times 0.127 \times 1.3} = 6872.53 \ N/m^3$$

$$\therefore \phi^2_{g_{oExp.}} = \frac{(\Delta P/\Delta Z)_{Exp.}}{(\Delta P/\Delta Z)_{f_o}} = \frac{228.4}{6872.53} = \underline{0.03323}$$

By computer, $\phi^2_{g_{o_{Exp.}}} = \underline{0.03319}$

(ii) Homogeneous Model

Input gas volume fraction, $\beta = \frac{Q_g}{Q_f+Q_g} = \frac{0.27856}{0.28526}$

$= 0.97651$

Input liquid volume fraction, $1 - \beta = 0.02349$

Mixture viscosity, $\mu_H = \beta\mu_g + (1-\beta)\mu_f$

$= (1.8043 + 2.0203) \times 10^{-5} = 3.8246 \times 10^{-5} \frac{NS}{m^2}$

Mixture Reynolds number $= \frac{GD}{\mu_H} = \frac{70.578}{3.8246 \times 10^{-5}}$

$= 1,845,370.6$

Mixture friction factor, for Re $>$ 100,000

$$\lambda_H = 0.2122\ Re_H^{0.2219} = 0.008636$$

$$\left(\frac{\Delta p}{\Delta z}\right)_H = \frac{\lambda_H G^2}{2D}\left(\frac{x}{\rho_g} + \frac{1-x}{\rho_f}\right)$$

$$= \frac{0.008636 \times (555.728)^2}{2 \times 0.127}\left[\frac{0.051436}{1.3} + \frac{0.948564}{996.67}\right]$$

$$= 425.44\ N/m^3$$

$$\phi^2_{f_{o_{HOM.}}} = \frac{(\Delta p/\Delta z)_{HOM}}{(\Delta p/\Delta z)_{f_o}} = \frac{425.44}{21.69} = \underline{19.615}$$

By computer, $\phi^2_{f_{o_{HOM}}} = \underline{19.582}$

Also

$$\phi^2_{g_{o_{HOM}}} = \frac{(\Delta P/\Delta Z)_{HOM}}{(\Delta P/\Delta Z)_{f_o}} = \frac{425.44}{6872.53} = \underline{0.061904}$$

By computer, $\phi^2_{g_{o_{HOM.}}} = \underline{0.06187}$

(iii) Baroczy Correlation

$$\text{Property index} = \left(\frac{\mu_f}{\mu_g}\right)^{0.2}\left(\frac{\rho_g}{\rho_f}\right) = \left(\frac{860.18 \times 10^{-6}}{1.8477 \times 10^{-5}}\right)^{0.2}\left(\frac{1.3}{996.67}\right)$$

$$= 0.0028117$$

Quality x = 0.051436

From $\phi^2_{f_o}$ versis x graph for different values of property index, we get

$$\phi^2_{f_{o_{BAR.}}} \simeq 27.1$$

$G = 555.7284, \quad \therefore \frac{G}{G_o} = 0.41$

By interpolation from $\frac{G}{G_o} = 0.5$ and for x = 0.056 (or 5.6%), we get the two phase multiplier ratio $\simeq$ 1.1

$$\therefore \phi^2_{f_{o_{BAR.}}} = 27.3 \times 1.13 = \underline{29.8}$$

By computer, $\phi^*_{f_{o_{BAR.}}} = \underline{29.24}$

(iv) Chenoweth-Martin Correlation

Liquid volume fraction, $1 - \beta = 0.02349$

the parameter $Z = \dfrac{(\Delta P/\Delta Z)_{g_o}}{(\Delta P/\Delta Z)_{f_o}} = \dfrac{\lambda_{g_o}}{\lambda_{f_o}} \dfrac{\rho_f}{\rho_g}$

$\lambda_{f_o} = 0.017781$, $\lambda_{g_o} = 0.007348$

$$\therefore \quad Z = \frac{0.007348}{0.017781} \; \frac{996.67}{1.3} = 316.827$$

From tables of Z vs $1-\beta$ given in Appendix T,

$$\phi^2_{f_{o_{CH-MR}}} = \underline{25.8}$$

By computer, $\phi^2_{f_{o_{CH-MR}}} = \underline{25.43}$

(v) <u>Chisholm Correlation</u>

$$\Gamma = \left(\frac{(\Delta P/\Delta Z)_{g_o}}{(\Delta P/\Delta Z)_{f_o}}\right)^{\frac{1}{2}} = \left(\frac{6872.53}{21.69}\right)^{\frac{1}{2}} = 17.8$$

$$\lambda = 0.2122 \; Re^{-0.2219}$$

Hence $n = 0.2219$, $2-n = 1.7781$

and $\frac{2-n}{2} = 0.88905$, also $x = 0.051436$

$$\phi^2_{f_{o_{CH.}}} = 1 + (\Gamma^2 - 1)\left[B\, x^{\frac{2-n}{2}} (1-x)^{\frac{2-n}{2}} + x^{2-n}\right]$$

For Γ in the range 9.5 to 28 and $G \leqslant 600$,

$$B = \frac{520}{\Gamma G^{\frac{1}{2}}} = \frac{520}{17.8 \times (555.728)^{\frac{1}{2}}} = 1.239$$

$$(x)^{\frac{2-n}{2}} = (0.051436)^{0.88905} = 0.07149$$

$$(1-x)^{\frac{2-n}{2}} = (0.948564)^{0.88905} = 0.95414$$

$$B\ (x)^{\frac{2-n}{2}}\ (1-x)^{\frac{2-n}{n}} = 0.084514$$

$$x^{2-n} = (0.051436)^{1.7781} = 0.0051109$$

$$\therefore\ \phi^2_{f_{o_{CH}}} = 1 + (316.84 - 1)(0.089623 + 0.0051109)$$

$$= \underline{29.31}$$

By computer, $\phi^2_{f_{o_{CH.}}} = \underline{29.27}$

(vi) <u>Lockhart-Martinelli Correlation</u>

$$\left(\frac{\Delta p}{\Delta Z}\right)_f = \frac{\lambda_f G^2}{2D\ \rho_f}\ (1 - x)^2$$

$$Re_f = (1 - 0.051436)(82050.25) = 77829.9$$

For $Re < 100{,}000$

$$\lambda_f \simeq 0.01828$$

$$\left(\frac{\Delta p}{\Delta Z}\right)_f = \frac{0.01828 \times (555.728)^2 \times (0.948564)^2}{2 \times 0.127 \times 996.67}$$

$$= 20.066\ N/m^3$$

Also $\left(\frac{\Delta p}{\Delta Z}\right)_f = \frac{\lambda_g\ G^2\ x^2}{2D\ \ \rho_g}$

$$Re_g = (0.051436)(3819775.4) = 196474.0$$

for Re > 100,000

$$\lambda_g = 0.2122\ Re_g^{-0.2219} = 0.014195$$

$$\left(\frac{\Delta P}{\Delta Z}\right)_g = \frac{0.014195 \times (555.728)^2 \times (0.051436)^2}{2 \times 0.127 \times 1.3} = 35.125\ \frac{N}{m^3}$$

The Lockhart-Martinelli parameter

$$X_{LM} = \frac{(\Delta P/\Delta Z)_f}{(\Delta P/\Delta Z)_g}^{\frac{1}{2}} = \left[\frac{20.066}{35.125}\right]^{\frac{1}{2}} = 0.75583$$

From tables in Appendix (T),

$$\phi_{f_{LM}} = 4.8837$$

$$\therefore \phi^2_{f_{LM}} = 23.85$$

Also

$$\phi_{g_{LM}} = 3.655$$

$$\therefore \phi^2_{g_{LM}} = 13.357$$

But, $\phi^2_{f_{LM}} = \frac{(\Delta P/\Delta Z)_{tp}}{(\Delta P/\Delta Z)_f}$, $\phi^2_{f_{o_{LM}}} = \frac{(\Delta P/\Delta Z)_{tp}}{(\Delta P/\Delta Z)_{f_o}}$

$$\therefore \phi^2_{f_{o_{LM}}} = \phi^2_{f_{LM}} \frac{(\Delta P/\Delta Z)_f}{(\Delta P/\Delta Z)_{f_o}} = \phi^2_{f_{LM}} \frac{\lambda_f}{\lambda_{f_o}} \quad (1 - x)^2$$

$$\phi^2_{f_{o_{LM}}} = (23.85)\left(\frac{0.01828}{0.017781}\right)(0.948564)^2$$

$$= \underline{22.0}$$

By computer, $\phi^2_{f_{o_{LM}}} = \underline{21.59}$

Also $\phi^2_{g_{o_{LM}}} = \phi^2_{g_{LM}} \frac{\lambda_g}{\lambda_{g_o}} x^2 = (3.655)^2 (\frac{0.014195}{0.007348}) (0.051436)^2$

$= \underline{0.06827}$

By computer $= \underline{0.06776}$

(vii) Dukler Case II

$$\left(\frac{\Delta p}{\Delta Z}\right)_D = \frac{\lambda_{tp}}{2D} \frac{G^2}{{}_{tp}} \psi$$

$\rho_{tp} = \beta \rho_g + (1 - \beta) \rho_f$ and $= 0.97651$

$\therefore \rho_{tp} = 0.97651 \times 1.3 + 0.02349 \times 996.67$

$= 24.68$ Kg/m^3

$\psi = \frac{\rho_f}{\rho_g} \frac{(1 - \beta)^2}{(1 - \alpha)} + \frac{\rho_g}{\rho_{tp}} \frac{\beta^2}{\alpha}$ with $\alpha = 0.864$

$= \frac{996.67}{24.681} \frac{(0.02349)^2}{0.136} + \frac{1.3}{23.412} \frac{(0.97651)^2}{0.864}$

$= 0.2251$

Let $N = - \ln (1 - \beta) = - \ln (0.02349) = 3.7512$

$$\lambda_{tp} = \lambda_1 \left[1 + \frac{N}{1.281+0.478N+0.444N^2-0.094N^3+0.00843N^4}\right]$$

$= \lambda_1 (1 + \frac{3.7512}{2.4432}) = 2.5354 \lambda_1$

$$\mu_{tp} = \beta\mu_g + (1-\beta)\mu_f = 3.8246 \times 10^{-5}$$

$$Re = \frac{70.578 \times 0.2251}{3.8246 \times 10^{-5}} = 415392.7$$

$$\lambda_1 = 0.2122 \quad Re^{-0.2219} = 0.012022$$

$$\lambda_{tp} = 2.5354 \times 0.01204 = 0.30482$$

$$\left(\frac{\Delta P}{\Delta Z}\right)_{tp} = \frac{0.030482 \times (555.728)^2 \times 0.2251}{2 \times 0.127 \times 24.681}$$

$$= 338.02 \ N/m^3$$

$$\phi^2_{f_{o_D}} = \frac{(\Delta P/\Delta Z)_{tp}}{(\Delta P/\Delta Z)_{f_o}} = \frac{338.02}{21.69} = \underline{15.584}$$

By computer, $\phi^2_{f_{o_D}} = \underline{15.37}$

APPENDIX V COMPUTER PROGRAM FOR THE FRICTION MULTIPLIERS CALCULATIONS

APPENDIX V COMPUTER PROGRAM FOR THE FRICTION MULTIPLIERS CALCULATIONS

NOMENCLATURE

R, RR	: Friction Factor = $(RR)(Re)^{-R}$
CRF, CRG, CRH, CRD, CRLMF, CRLMG	: Counters used to indicate the range of Reynold's number for liquid, gas, homogeneous, Dukler, L-M liquid and L-M gas, and are used in subroutine RETEST. JJ = 1 $15,000 < Re < 100,000$ JJ = 1 $Re < 2,000$ JJ = 2 $Re > 100,000$ JJ = 0 $2,000 < Re < 15,000$
TME, TMEG, TMH TMHG, TMD, TMCM, TMCH, TMLMF, TMLHG, TMB	Experimental Liquid, Experimental Gas, Homogeneous Liquid, Homogeneous Gas, Dukler, Chenoweth-Martin, Chisholm, Lock.-Mart. Liquid, Lock.-Mart. Gas and Baroczy, Two Phase Friction Multipliers respectively.
TERM	Momentum term
GTOT, GTOTL	Total mass velocity
QUALTY	Quality
PINDX, C	Property index (Baroczy)
CHLMZ	$\left[(dp/dZ)_{g_o}/(dp/dZ)_{f_o}\right]^{\frac{1}{2}}$
RFT, RGT, RH, RD, RFLM, RGLM	Experimental Liquid, Experimental Gas, Homogeneous, Dukler, Lock.-Mart. Liquid, and Lock.-Mart. Gas Re numbers respectively.
FFT, FGT, FH, FD, FFLM, FGLM	Experimental Liquid, Experimental Gas, Homogeneous, Dukler, Lock.-Mart. Liquid and Lock.-Mart. Gas Friction Factor respectively.

PFT	Pressure drop based on total mass flowrate flowing as liquid.
PGT	Pressure drop based on total mass flowrate flowing as gas
PH, PD,	Pressure drop for homogeneous and Dukler respectively.
E, PSY, VD	Terms used in Dukler correlation
BCH	Chisholm Factor
WG, WF	Laminar-Laminar Gas and Liquid (L-M)
TTG, TTF	Turbulent-Turbulent Gas and Liquid (L-M)
VTG, VTF	Laminar-Turbulent Gas and Liquid (L-M)
TVG, TVF	Turbulent-Laminar Gas and Liquid (L-M)
BETA, B	Input volume fraction
C1, C2, C3, C4, C5, C6	Uncorrected two phase friction multipliers (Baroczy)
RTMB	Two phase friction multiplier ratio
SLBRYS	Intermittent side of the boundary with separated flow
STBRY	Separated side of the boundary with intermittent flow
SLBRYA	Slug side of the boundary with annular flow
ANBRY	Annular side of the boundary with intermittent flow
FRF	Liquid Froude number based on superficial velocity
FRDM	Mixture Froude number based on superficial velocities

SLIPR	Slip ratio = U_g/U_f
SLIP	Slip = $U_g - U_f$
WEBM	Mixture Weber number based on superficial velocities
RUS	U_{sg}/U_{sf}
RVD	α/B
FRG	Gas Froude number based on superficial velocity

SUBROUTINE CONVERSION : Converts raw data into useful information.

SUBROUTINE RETEST : Calculates friction factor using the tube friction characteristic

SUBROUTINE CORRECTION : Calculates the mass velocity correction factor for Baroczy.

```
      PROGRAM(TPDC2)
      OUTPUT6=LP0
      INPUT 5=CR0
      END
      MASTER TPDC2
C
C     THIS PROGRAM COMPUTES THE EXP. TWO PHASE MULTIPLIERS
C     FOR BOTH GAS AND LIQUID.ALSO IT DETERMINES THE
C     MULTIPLIERS USING THE HOMOGENEOUS MODEL,DUKLER,CHISHOLM,
C     CHENOWETH-MARTIN,BAROCZY,AND LOCKHART-MARTINELLI CORRELATIONS.
C     THE DATA PRESENTED HERE ARE FOR 8.5 INCH BORE PERSPEX
C     PIPE WITH AIR AND WATER AS THE TWO COMPONENTS BEING  MIXED
C     AT THE BEGINING OF TEST SECTION.PRESSURE READINGS WERE TAKEN
C     AT A METRE INTERVAL ALONG THE TEST SECTION.
C
      COMMON DG1,DG2,DG3,N(370),T(370),P(370),VDF(370),DF(370),
     1DG(370),PE(370),QF(370),QG(370),WG(370),K(370),D,PI,AP,
     2M,STN(370),R,RR,VGG(370),VFF(370)
      INTEGER CRF,CRG,CRH,CRD,CRLMF,CRLMG
      DIMENSION TME(370),TMH(370),TMD(370),TMCH(370),TMCM(370),
     1TMLMF(370),TMLMG(370),TMEG(370),TMHG(370),TMDG(370),
     2TMB(370),TERM(370),CRF(370),CRG(370),CRH(370),CRD(370),
     3CRLMF(370),CRLMG(370),USF(370),USG(370),CHLMZ(370),
     4TG(370),BETA(370),GTOTL(370),QALTY(370),PINDX(370)
C     K=1       BUBBLE
C     K=2       SLUG
C     K=3       STRATIFIED
C     K=4       WAVY
C     K=5       ANNULAR
C     K=6       PLUG
C     K=44      UNSETTLED WAVY FLOW.LIQUID LEVEL BUILDS UP
C               DOWN STREAM
C     CR=-1      RE LT 2000
C     CR=0       RE GT 2000 AND RE LT 20000
C     CR=1       RE LT 100000 AND RE GT 20000
C     CR=2       RE GT 100000
```

```
      CALL CONVERSION
      GASCT=.000287
      GTOTH=4000.0
      DDZ=2.5
      GRVTY=9.807
      R1=(2-R)/2
      R2=2*R1
      DO 20 I=1,M
      VG=VGG(I)
      VF=VFF(I)
      USF(I)=QF(I)/AP
      USG(I)=QG(I)/AP
C     START OF P/Z CALCULATION
      GTOT=(QF(I)*DF(I)+QG(I)*DG(I))/AP
      GTOTL(I)=GTOT
      RFT=GTOT*D/VF
      CALL RETEST(RFT,FFT,CRF(I))
3     PFT=FFT*GTOT**2/(2*D*DF(I))
      IF(QF(I).EQ.0.0.AND.QG(I).EQ.0.0)GO TO 20
      TME(I)=PE(I)/PFT
      RGT=GTOT*D/VG
      CALL RETEST(RGT,FGT,CRG(I))
9     PGT=FGT*GTOT**2/(2*D*DG(I))
      TMEG(I)=PE(I)/PGT
      IF(RFT.LT.15000..AND.RFT.GT.2000.)TME(I)=0.0
      IF(RGT.LT.15000..AND.RGT.GT.2000.)TMEG(I)=0.0
C     HOMOGENEOUS MODEL
      X=QG(I)*DG(I)/(GTOT*AP)
      QALTY(I)=X
      B=QG(I)/(QF(I)+QG(I))
      BETA(I)=B
      G=1-B
      A=ALOG(G)
      ZGTOT=(GTOT/GTOTH)**B
      VH=VF*(1.0+DDZ*B)*ZGTOT
      RH=GTOT*D/VH
      CALL RETEST(RH,FH,CRH(I))
5     PH=FH*GTOT**2*(1.0/(B*DG(I)+(1-B)*DF(I)))/(2*D)
      TMH(I)=PH/PFT
      TMHG(I)=PH/PGT
      IF(RH.LT.15000..AND.RH.GT.2000.)TMH(I)=0.0
      IF(RH.LT.15000..AND.RH.GT.2000.)TMHG(I)=0.0
      IF(RFT.LT.15000..AND.RFT.GT.2000.)TMH(I)=0.0
      IF(RGT.LT.15000..AND.RGT.GT.2000.)TMHG(I)=0.0
C     DUKLER CORRELATION
      IF(VDF(I).EQ.0.0)GO TO 6
      DD=B*DG(I)+G*DF(I)
      F=-ALOG(G)
      E=1.281-.478*F+.444*F**2-.094*F**3+.00843*F**4
      PSY=DF(I)*G**2/(DD*(1-VDF(I)))+DG(I)*B**2/(DD*VDF(I))
      VD=B*VG+G*VF
      RD=GTOT*D*PSY/VD
      CALL RETEST(RD,FD,CRD(I))
7     FFD=FD*(1+F/E)
      PD=FFD*GTOT**2*PSY/(2*D*DD)
      TMD(I)=PD/PFT
      TMDG(I)=PD/PGT
      IF(RD.LT.15000..AND.RD.GT.2000.)GO TO 6
      GO TO 10
6     TMD(I)=0.0
      TMDG(I)=0.0
```

```
C     CHISHOLM CORRELATION
10    Z=FGT*DF(I)/(FFT*DG(I))
      ZI=Z**.5
      IF(RFT.LT.15000..AND.RFT.GT.2000.)GO TO 35
      IF(RGT.LT.15000..AND.RGT.GT.2000.)GO TO 35
      IF(ZI.LE.9.5)GO TO 25
      IF(ZI.GT.9.5.AND.ZI.LT.28)GO TO 26
      BCH=15000/(Z*GTOT**.5)
      GO TO 27
25    IF(GTOT.LE.500)GO TO 28
      IF(GTOT.GT.500.AND.GTOT.LT.1900)GO TO 29
      BCH=55/GTOT**.5
      GO TO 27
28    BCH=4.8
      GO TO 27
29    BCH=2400/GTOT
      GO TO 27
26    IF(GTOT.LE.600)GO TO 30
      BCH=21/Z**.5
      GO TO 27
30    BCH=520/(ZI*GTOT**.5)
27    TMCH(I)=1+(Z-1)*(BCH*X**(R1)*(1-X)**(R1)+X**(R2))
      CHLMZ(I)=ZI
      IF(VDF(I).EQ.0.0)GO TO 33
      TK=T(I)+273
      TERM(I)=1-GTOT**2*(X**2*TK*GASCT/(VDF(I)*P(I)**2))
C     CHENOWETH MARTIN CORRELATION
C     FOR LIQUID VOLUME FRACTION LESS THAN .007,ERROR MESSAGE
C     IS PRODUCED SETTING THE TWO PHASE MULTIPLIER TO ZERO.
C     EXTENSION OF THE RANGE OF THE POLYNOMIAL FIT IS REQUIRED
C     FOR SMALLER VALUES OF "B".
33    IF(G.GE..07)GO TO 11
      IF(Z.LE.50)GO TO 12
      IF(Z.LE.100)GO TO 13
      IF(Z.LE.200)GO TO 14
      IF(Z.GT.200.AND.Z.LE.500) GO TO 15
      B500=65.31393539+82.59327014*A+41.00736661*A**2+8.812604934*A**3
     1+.7983872946*A**4
      TMCM(I)=B500
      GO TO 40
11    B0=.9984778757-1.031743707*A+.03145126553*A**2-.3157101727*A**3
      TMCM(I)=B0
      GO TO 40
12    B50=4.870768633+4.314395825*A+2.337328508*A**2
      TMCM(I)=B50-(1-Z/50)*B50
      GO TO 40
13    B100=23.1320003+17.34038494*A+4.212264895*A**2-.157322532*A**3
      B50=4.870768633+4.314395825*A+2.337328508*A**2
      TMCM(I)=B50+(Z/50-1)*(B100-B50)
      GO TO 40
14    B200=-.4002432041-.2335712751*A+2.696966803*A**2+1.105942557*A**3
     1+.2292410911*A**4
      B100=23.1320003+17.34038494*A+4.212264895*A**2-.157322532*A**3
      TMCM(I)=B100+(Z/100-1)*(B200-B100)
      GO TO 40
15    B500=65.31393539+82.59327014*A+41.00736661*A**2+8.812604934*A**3
     1+.7983872946*A**4
      B200=-.4002432041-.2335712751*A+2.696966803*A**2+1.105942557*A**3
     1+.2292410911*A**4
      TMCM(I)=B200+(B500-B200)*(Z-200)/300
40    IF(G.LT..007)TMCM(I)=0.0
```

```
C     LOCKHART MARTINELLI CORRELATION
[redacted]
C     LOCK-MART CORRELATION IS EXTENDED FOR XLM > 100
C     AND LESS OR EQUAL TO 1000
      GO TO 31
35    TMCH(I)=0.0
      TMCM(I)=0.0
31    RFLM=(1-X)*GTOT*D/VF
      IF(RFLM.EQ.0.0)GO TO 66
      CALL RETEST(RFLM,FFLM,CRLMF(I))
      IF(RFLM.LT.15000..AND.RFLM.GT.2000.)GO TO 66
32    RGLM=X*GTOT*D/VG
      IF(RGLM.EQ.0.0)GO TO 66
      CALL RETEST(RGLM,FGLM,CRLMG(I))
      IF(RGLM.LT.15000..AND.RGLM.GT.2000.)GO TO 66
34    XLM=((1-X)/X)*(FFLM*DG(I)/(FGLM*DF(I)))**.5
      A=ALOG(XLM)
      IF(XLM.GT.100)GO TO 57
      IF(RFLM.GT.2000.AND.RGLM.GT.2000) GO TO 50
      IF(RFLM.LE.2000.AND.RGLM.GT.2000) GO TO 52
      IF(RFLM.GT.2000.AND.RGLM.LE.2000) GO TO 54
      IF(XLM.LT.1) GO TO 56
      VVG2=2.610404687+.101283467*A+5.726725265*A**2-6.310718705*A**3
     1+4.280192873*A**4-1.427159734*A**5+.2442578117*A**6
     2-.01584725635*A**7
      VVF2=2.609930397-1.097911043*A+.5583817165*A**2-.1951651221*A**3
     1+.03620386668*A**4-.002659685406*A**5
      TMLMF(I)=VVF2**2
      TMLMG(I)=VVG2**2
      GO TO 60
56    VVF1=2.60997411-1.025208328*A+.9193521817*A**2+.4503779331*A**3
     1+.5050558188*A**4+.1382119158*A**5+.01900414834*A**6
      VVG1=2.61007206+1.475223603*A+.6420600964*A**2+.1302008707*A**3+
     1.002216135198*A**4-.003097175991*A**5-.0003227634316*A**6
      TMLMF(I)=VVF1**2
      TMLMG(I)=VVG1**2
      GO TO 60
50    IF(XLM.LT.1) GO TO 51
      TTF2=4.199938412-2.051851893*A+.9008215725*A**2-.4161997166*A**3
     1+.1394900102*A**4-.02451068379*A**5+.001670453502*A**6
      TTG2=4.200117503+2.287848357*A+.3043882286*A**2+1.2277525144*A**3
     1-.9313047181*A**4+.3976301436*A**5-.07085705889*A**6+.0053
     276857115*A**7
      TMLMF(I)=TTF2**2
      TMLMG(I)=TTG2**2
      GO TO 60
51    TTF1=4.199281747-2.477469389*A-1.684998137*A**2-5.040648902*A**3
     1-3.897981432*A**4-1.588436339*A**5-.3029787767*A**6
     2-.02296824998*A**7
      TTG1=4.199943529+2.312901027*A+1.551428201*A**2+1.102259514*A**3
     1+.5371038997*A**4+.1490180927*A**5+.02124923531*A**6
     2+.00120931503*A**7
      TMLMF(I)=TTF1**2
      TMLMG(I)=TTG1**2
      GO TO 60
52    IF(XLM.LT.1) GO TO 53
      VTF2=3.48000021-1.764228833*A+1.290241065*A**2-1.122938442*A**3
     1+.6231952608*A**4-.1870006156*A**5+.02820821765*A**6
     2-.001683874959*A**7
      VTG2=3.480333245-4.201908418*A+21.54483951*A**2-25.80776402*A**3
     1+15.69941316*A**4-4.897974195*A**5+.7715782588*A**6
     2-.04747326846*A**7
```

```
       TMLMF(I)=VTF2**2
      TMLMG(I)=VTG2**2
      GO TO 60
 53   VTF1=3.479441823-1.111333064*A+1.810215402*A**2+.9576921726*A**3
     1+.5605476801*A**4+.09663830564*A**5+.01201352676*A**6
      VTG1=3.480064648+2.280113539*A+1.863252128*A**2+1.42330111*A**3
     1+.7175259202*A**4+.2048822674*A**5+.03013049794*A**6
     2+.001776677817*A**7
      TMLMF(I)=VTF1**2
       TMLMG(I)=VTG1**2
      GO TO 60
 54   IF(XLM.LT.1) GO TO 55
      TVF2=3.480032223-2.396720733*A+3.041953583*A**2-2.799168943*A**3
     1+1.424601836*A**4-.3952810053*A**5+.05633372155*A**6
     2-.003228419148*A**7
      TVG2=3.480856386-8.945210048*A+36.3454554*A**2-42.89041856*A**3
     1+25.60232101*A**4-7.932419743*A**5+1.238134934*A**6
     2-.07576584718*A**7
      TMLMF(I)=TVF2**2
      TMLMG(I)=TVG2**2
      GO TO 60
 55   TVF1=3.48029967-1.534967516*A-.11094655*A**2-1.489976001*A**3
     1-.8786798354*A**4-.3288376218*A**5-.05543108066*A**6
     2-.004578245644*A**7
      TVG1=3.480049097+2.047775767*A+.8109023841*A**2+.02182375062*A**3
     1-.1469529208*A**4-.0665664344*A**5-.01208375752*A**6
     2-.0008077979251*A**7
      TMLMF(I)=TVF1**2
      TMLMG(I)=TVG1**2
      GO TO 60
C     EXTENSION OF THE CORRELATION
 57   TMLMG(I)=ALOG(111.)+.8489831*ALOG(XLM/100.)
      TMLMF(I)=ALOG(1.11)-.04532298*ALOG(XLM/100.)
      TMLMG(I)=(EXP(TMLMG(I)))**2
      TMLMF(I)=(EXP(TMLMF(I)))**2
      GO TO 60
 66   TMLMF(I)=0.0
      TMLMG(I)=0.0
 60   TMLMF(I)=TMLMF(I)*(1-X)**2*(FFLM/FFT)
      TMLMG(I)=TMLMG(I)*X**2*(FGLM/FGT)
      IF(RFT.LT.15000..AND.RFT.GT.2000.)GO TO 42
      GO TO 44
 42   TME(I)=0.0
      TMH(I)=0.0
      TMD(I)=0.0
 44   IF(RGT.LT.15000..AND.RGT.GT.2000.)GO TO 43
      GO TO 45
 43   TMEG(I)=0.0
      TMHG(I)=0.0
      TMDG(I)=0.0
C     BAROCZY CORRELATION
C     FOR QUALITIES LESS THAN .000001 ,THE BAROCZY MULT. IS SET TO 1.0 .

C     THE PROGRAM IS VALID FOR X LESS OR EQUAL TO 0.4. FOR 89GHN9
C      VALUES,ERROR MESSAGE IS PRODUSED SETTING "TMB" TO ZERO.
C     THE SAME MESSAGE APPEARS WHEN C EXCEEDS .005.
 45   PE(I)=PE(I)/1000.
      IF(X.EQ.0.0)GO TO 22
      A=ALOG(X)
      C=(DG(I)/DF(I))*(VF/VG)**.2
      PINDX(I)=C
```

```
      IF(X.LT..001.AND.X.GE..000001)GO TO 64
      IF(X.LT..000001)GO TO 65
      IF(C.GE..001.AND.C.LE..002)GO TO 61
      IF(C.GT..002.AND.C.LE..003)GO TO 62
      IF(C.GT..003.AND.C.LE..004)GO TO 63
      C5=5.242938204+.836212894*A+.0256860441*A**2
      C4=5.474991751+.8798436666*A+.0280732611*A**2
      C4=EXP(C4)
      C5=EXP(C5)
      TMB(I)=C4+(C5-C4)*(C-.004)/.001
      GO TO 70
61    C1=6.761433864+.9264567065*A-.1743093806*A**2-.05057031267*A**3
     1-.00349081 0436*A**4
      C2=6.172327345+1.067502975*A+.04101449738*A**2
      C1=EXP(C1)
      C2=EXP(C2)
      TMB(I)=C1+(C2-C1)*(C-.001)/.001
      GO TO 70
62    C2=6.172327345+1.067502975*A+.04101449738*A**2
      C3=5.755718441+.9450772699*A+.03166408673*A**2
      C2=EXP(C2)
      C3=EXP(C3)
      TMB(I)=C2+(C3-C2)*(C-.002)/.001
      GO TO 70
63    C4=5.474991751+.8798436666*A+.0280732611*A**2
      C3=5.755718441+.9450772699*A+.03166408673*A**2
      C3=EXP(C3)
      C4=EXP(C4)
      TMB(I)=C3+(C4-C3)*(C-.003)/.001
70    IF(X.GT..4.OR.C.GT..005)TMB(I)=0.0
      GO TO 21
64    C6=13.96575981+3.183123805*A+.2619656081*A**2+.007202603753*A**3
      TMB(I)=C6
      GO TO 21
65    TMB(I)=1.0
21    CONTINUE
      IGTOT=IFIX(GTOT)
      IF(X.LT.0.001)GO TO 22
      IF(IGTOT.EQ.1356)TMB(I)=1.0
      IF(IGTOT.EQ.1356)GO TO 22
      IF(IGTOT.LE.339)GO TO 95
      IF(IGTOT.GT.339.AND.IGTOT.LT.678)GO TO 100
      IF(IGTOT.GE.678.AND.IGTOT.LT.1356)GO TO 105
      IF(IGTOT.GT.1356.AND.IGTOT.LT.2712)GO TO 110
      IF(IGTOT.GE.2712.AND.IGTOT.LT.4068)GO TO 115
      IF(IGTOT.GE.4068)GO TO 120
95    CALL CORRECTION(X,C,339,RTMB)
      TMB(I)=RTMB*TMB(I)
      GO TO 22
100   CALL CORRECTION(X,C,339,RTMB0)
      CALL CORRECTION(X,C,678,RTMB1)
      A=(RTMB0-RTMB1)/(678-339)
      RTMB=RTMB0-A*(GTOT-339.0)
      TMB(I)=RTMB*TMB(I)
      GO TO 22
```

```
105   CALL CORRECTION(X, C, 678, RTMB1)
      CALL CORRECTION(X, C, 1356, RTMB2)
      A=(RTMB1-RTMB2)/(1356-678)
      RTMB=RTMB1-A*(GTOT-678.0)
      TMB(I)=RTMB*TMB(I)
      GO TO 22
110   CALL CORRECTION(X, C, 1356, RTMB2)
      CALL CORRECTION(X, C, 2712, RTMB3)
      A=(RTMB2-RTMB3)/(2712-1356)
      RTMB=RTMB2-A*(GTOT-1356.0)
      TMB(I)=RTMB*TMB(I)
      GO TO 22
115   CALL CORRECTION(X, C, 2712, RTMB3)
      CALL CORRECTION(X, C, 4068, RTMB4)
      A=(RTMB3-RTMB4)/(4068-2712)
      RTMB=RTMB3-A*(GTOT-2712)
      TMB(I)=RTMB*TMB(I)
      GO TO 22
120   CALL CORRECTION(X, C, 4068, RTMB4)
      TMB(I)=RTMB4*TMB(I)
22    IF(X.EQ.0.0)TMB(I)=0.0
      WRITE(6, 125)N(I), VDF(I), PE(I), TME(I), TMEG(I), TMH(I),
     1TMHG(I), TMLMF(I), TMLMG(I), TMCM(I), TMB(I), TMCH(I), TMD(I), K(I)
125   FORMAT(/, I8, 2F8.4, 10F8.2, I6)
20    CONTINUE
      DO 900 I1=1, M, 13
      WRITE(6, 906)
906   FORMAT(1H1, //////////)
      WRITE(6, 901)
901   FORMAT(3X, 4HTEST, 3X, 4HTEMP, 2X, 6HP MEAN, 2X, 4HVOID, 2X,
     110HWATER FLOW, 9H AIR FLOW, 8H DENSITY, 2X, 7HDENSITY, 5X,
     217HSETTLING LENGTH, L, 3X, 5HMETRE, 5X, 7HPR-GRAD, 3X, 4HFLOW)
      WRITE(6, 907)
907   FORMAT(3X, 3HRUN, 18X, 5HFRCTN, 4X, 4HRATE, 6X, 4HRATE, 4X, 5HWATER, 5X,
     13HAIR, 7X, 5HINLET, 5X, 6HOUTLET, 3X, 10HFLOW PATRN)
      WRITE(6, 902)
902   FORMAT(4X, 2HNO, 5X, 1HC, 4X, 5HKN/M2, 11X, 6HM3/SEC, 4X, 6HM3/SEC,
     13X, 5HKG/M3, 4X, 5HKG/M3, 4X, 1HL, 4X, 3HL/D, 3X, 1HL, 4X, 3HL/D, 3X,
     21HL, 4X, 3HL/D, 3X, 5HKN/M3, 3X, 7HPATTERN)
      I2=I1+12
      DO 1000 I=I1, I2
      IF(I.EQ.M+1)GO TO 705
      IF(PE(I).EQ.0.0.AND.VDF(I).EQ.0.0)GO TO 840
      IF(PE(I).EQ.0.0)GO TO 850
      IF(VDF(I).EQ.0.0)GO TO 860
      WRITE(6, 904)N(I), T(I), P(I), VDF(I), QF(I), QG(I), DF(I), DG(I),
     1PE(I), K(I)
904   FORMAT(/I8, F6.1, F8.2, F7.3, 2F10.6, F8.2, F8.4, 36X, F7.5, I6)
      GO TO 1000
840   WRITE(6, 845)N(I), T(I), P(I), QF(I), QG(I), DF(I), DG(I), K(I)
845   FORMAT(/I8, F6.1, F8.2, 3X, 2H--, 2X, 2F10.6, F8.2, F8.4, 39X, 2H--, 2X, I6)
      GO TO 1000
850   WRITE(6, 855)N(I), T(I), P(I), VDF(I), QF(I), QG(I), DF(I), DG(I), K(I)
855   FORMAT(/I8, F6.1, F8.2, F7.3, 2F10.6, F8.2, F8.4, 39X, 2H--, 2X, I6)
      GO TO 1000
860   WRITE(6, 865)N(I), T(I), P(I), QF(I), QG(I), DF(I), DG(I), PE(I), K(I)
865   FORMAT(/I8, F6.1, F8.2, 3X, 2H--, 2X, 2F10.6, F8.2, F8.4, 36X, F7.5, I6)
1000  CONTINUE
      GO TO 707
705   WRITE(6, 711)
707   WRITE(6, 905)
905   FORMAT(//, 5X, 5HTABLE, 10X, 79HPRESSURE DROP, SETTLING LENGTH AND OTHE
     1R DATA DERIVED FROM EXPERIMENTAL READINGS)
```

```
900   CONTINUE
      DO 2000 I1=1,M,13
      WRITE(6,807)
807   FORMAT(1H1,//////////)
      WRITE(6,802)
802   FORMAT(2X,4HTEST,3X,4HVOID,3X,9HTWO-PHASE,28X,
     139HVALUES OF TWO-PHASE FRICTION MULTIPLIER)
      WRITE(6,803)
803   FORMAT(2X,3HRUN,11X,8HFRICTION)
      WRITE(6,804)
804   FORMAT(9X,5HFRCTN,2X,9HPRES-GRAD,5X,12HEXPERIMENTAL,6X,
     111HHOMOG MODEL,7X,9HLOCK-MART,8X,6HCH-MRT,2X,
     27HBAROCZY,2X,5HCHLSM,3X,6HDUCKLR)
      WRITE(6,805)
805   FORMAT(3X,2HNO,12X,5HKN/M3)
      I2=I1+12
      DO 3000 I=I1,I2
      IF(I.EQ.M+1)GO TO 709
      IF(TME(I).EQ.0.0.AND.TMLMF(I).EQ.0.0)GO TO 1300
      IF(TME(I).EQ.0.0)GO TO 1400
      IF(TMLMF(I).EQ.0.0)GO TO 1100
      WRITE(6,1001)N(I),VDF(I),PE(I),TME(I),TMEG(I),TMH(I),TMHG(I),
     1TMLMF(I),TMLMG(I),TMCM(I),TMB(I),TMCH(I),TMD(I)
1001  FORMAT(/I7,F8.4,F9.5,F10.3,F11.6,F7.3,F9.6,2F10.6,F8.3,
     13F8.3)
      GO TO 3000
1300  IF(VDF(I).EQ.0.0)GO TO 1700
      WRITE(6,1500)N(I),VDF(I),TMH(I),TMHG(I),TMCM(I),
     1TMB(I),TMCH(I),TMD(I)
1500  FORMAT(/I7,F8.4,5X,2H--,8X,2H--,8X,2H--,3X,
     1F7.3,F9.6,2(5X,2H--,3X),F8.3,3F8.3)
      GO TO 3000
1400  IF(VDF(I).EQ.0.0)GO TO 1800
      WRITE(6,1600)N(I),VDF(I),TMH(I),TMHG(I),TMLMF(I),TMLMG(I),
     1TMCM(I),TMB(I),TMCH(I),TMD(I)
1600  FORMAT(/I7,F8.4,5X,2H--,2X,6X,2H--,2X,6X,2H--,3X,F7.3,F9.6,
     12F10.6,F8.3,3F8.3)
      GO TO 3000
1100  WRITE(6,1200)N(I),VDF(I),PE(I),TME(I),TMEG(I),TMH(I),TMHG(I),
     1TMCM(I),TMB(I),TMCH(I),TMD(I)
1200  FORMAT(/I7,F8.4,F9.5,F10.3,F11.6,F7.3,F9.6,5X,2H--,8X,2H--,3X,
     1F8.3,3F8.3)
      GO TO 3000
1700  WRITE(6,1900)N(I),TMH(I),TMHG(I),TMCM(I),TMB(I),TMCH(I)
1900  FORMAT(/I7,4X,2H--,7X,2H--,8X,2H--,8X,2H--,3X,
     1F7.3,F9.6,2(5X,2H--,3X),F8.3,2F8.3,5X,2H--)
      GO TO 3000
1800  WRITE(6,1910)N(I),TMH(I),TMHG(I),TMLMF(I),TMLMG(I),TMCM(I),
     1TMB(I),TMCH(I)
1910  FORMAT(/I7,4X,2H--,7X,2H--,8X,2H--,8X,2H--,3X,F7.3,
     1F9.6,2F10.6,F8.3,2F8.3,5X,2H--)
3000  CONTINUE
      GO TO 708
709    WRITE(6,711)
711   FORMAT(//////)
708   WRITE(6,808)
808   FORMAT(//,10X,5HTABLE,30X,32HCOMPARISON OF FRICTION PRESSURE ,
     19HDROP DATA)
2000  CONTINUE
      WRITE(6,2100)
2100  FORMAT(1H1,//,3X,'NO',6X,'GTOTL',4X,'QALTY',
     15X,'PINDX',4X,'TMH',4X,'TME',6X,'USF',6X,
     2'USG',6X,'VDF',4X,'BETA',4X,'PATRN',2X,'CODE',2X,'CHLMZ',//)
```

```
      DO 5000 I=1,M
      FRF=USF(I)/((D*GRVTY)**0.5)
      SLBRYS=0.5*((1-BETA(I))**0.306)
      STBRY=0.473*((1-BETA(I))**0.390)
      SLBRYA=4.2*((1-BETA(I))**0.8875)
      ANBRY=5.2*((1-BETA(I))**0.7194)
      IF(FRF.LT.STBRY)NCODE=3
      IF(FRF.GT.SLBRYS.AND.FRF.LT.SLBRYA)NCODE=2
      IF(FRF.GE.STBRY.AND.FRF.LE.SLBRYS)NCODE=32
      IF(FRF.GT.ANBRY.AND.USF(I).LT.4.0)NCODE=5
      IF(FRF.GE.SLBRYA.AND.FRF.LE.ANBRY)NCODE=52
      IF(USF(I).GE.4.0)NCODE=2
      WRITE(6,4000)N(I),GTOTL(I),QALTY(I),PINDX(I),TMH(I),TME(I),
     1USF(I),USG(I),VDF(I),BETA(I),K(I),NCODE,CHLMZ(I)
 4000 FORMAT(/I8,F8.2,2F10.6,3X,F7.4,2X,5F8.4,2I5,F8.2)
 5000  CONTINUE
      WRITE(6,2600)
 2600 FORMAT(1H1,//,5X,'NO ',10X,'UG/UF',6X,'UG-UF',6X,'GTOTL',
     18X,'VDF',6X,'BETA',6X,'FRDM',6X,'WEBM',8X,'PATERN',//)
      DO 2500 I=1,M
      FRDM=((USF(I)+USG(I))**2)/(D*GRVTY)
      FRDM=ALOG(FRDM)
      IF(VDF(I).EQ.0.0)GO TO 2800
      UG=USG(I)/VDF(I)
      UF=USF(I)/(1.0-VDF(I))
      SLIPR=UG/UF
      SLIP=UG-UF
      DNSTYM=DG(I)*VDF(I)+DF(I)*(1.0-VDF(I))
      STN(I)=STN(I)/1000.0
      WEBM=((USG(I)+USF(I))**2)*D*DNSTYM/STN(I)
      GO TO 2900
 2800 SLIPR=0.0
      SLIP=0.0
      WEBM=0.0
 2900 WRITE(6,2700)N(I),SLIPR,SLIP,GTOTL(I),VDF(I),
     1BETA(I),FRDM,WEBM,K(I)
 2500 CONTINUE
 2700 FORMAT(/I8,6F12.4,F12.3,I10)
      WRITE(6,3050)
 3050 FORMAT(1H1,//,5X,'NO ',8X,'RUS',8X,'RVD',5X,'LN(FRG)',
     18X,'VDF',6X,'BETA',6X,'LN(FRF)',5X,'LN(REG)',5X,
     2'LN(REF)',4X,'PATERN',//)
      DO 3100 I=1,M
      RUS=USG(I)/USF(I)
      IF(BETA(I).EQ.0.0)GO TO 3200
      RVD=VDF(I)/BETA(I)
      FRG=ALOG((USG(I)**2)/(D*GRVTY))
      REG=D*DG(I)*USG(I)/VGG(I)
      REG=ALOG(REG)
      GO TO 3250
 3200 RVD=0.0
      FRG=0.0
      REG=0.0
 3250 FRF=ALOG((USF(I)**2)/(D*GRVTY))
      REF=D*DF(I)*USF(I)/VFF(I)
      REF=ALOG(REF)
      WRITE(6,3150)N(I),RUS,RVD,FRG,VDF(I),BETA(I),
     1FRF,REG,REF,K(I)
 3100 CONTINUE
 3150 FORMAT(/,I8,8F12.5,I10)
      STOP
      END
```

```
      SUBROUTINE RETEST(RE,FT,JJ)
      COMMON DG1,DG2,DG3,N(370),T(370),P(370),VDF(370),DF(370),
     1DG(370),PE(370),QF(370),QG(370),WG(370),K(370),D,PI,AP,
     2M,STN(370),R,RR,VGG(370),VFF(370)
      IF(RE.EQ.0.0)GO TO 1
      IF(RE.LT.2000)GO TO 2
      IF(RE.GE.100000)GO TO 4
      IF(D.GT.0.127)GO TO 4
      AR=ALOG(RE)
      FT=1084.055501-381.5544769*AR+50.26051543*AR**2
     1-2.94562527*AR**3+0.06476364087*AR**4
      FT=EXP(FT)
      JJ=1
      GO TO 8
4     FT=RR*RE**(-R)
      JJ=2
      GO TO 8
1     FT=0.0
      GO TO 8
2     FT=64/RE
      JJ=-1
8     IF(RE.LT.15000..AND.RE.GT.2000.)JJ=0
      RETURN
      END
      SUBROUTINE CORRECTION(X,C,IGTOT,RTMB)
      IF(IGTOT.EQ.339)GO TO 5
      IF(IGTOT.EQ.678)GO TO 10
      IF(IGTOT.EQ.1356)GO TO 15
      IF(IGTOT.EQ.2712)GO TO 20
      IF(IGTOT.EQ.4068)GO TO 25
5     RT1=1.581866908-225.6780954*C+38327.37361*C**2
     1-2025021.215*C**3
      RT2=RT1
      RT3=1.523982116-271.3031864*C+46610.53568*C**2
     1-2387801.69*C**3
      RT4=1.537467874-54.22916382*C+7339.63855*C**2
     1-354930.1629*C**3
      RT5=RT4
35    IF(X.LE.0.01)GO TO 40
      IF(X.LE.0.05)GO TO 41
      IF(X.LE.0.10)GO TO 42
      IF(X.LE.0.20)GO TO 43
40    AA=(RT1-RT2)/(0.01-0.001)
      RTMB=RT1-AA*(X-0.001)
      GO TO 30
41    AA=(RT2-RT3)/(0.05-0.01)
      RTMB=RT2-AA*(X-0.01)
      GO TO 30
42    AA=(RT3-RT4)/(0.10-0.05)
      RTMB=RT3-AA*(X-0.05)
      GO TO 30
43    AA=(RT4-RT5)/(0.20-0.10)
      RTMB=RT4-AA*(X-0.10)
      GO TO 30
10    RT1=1.252488916-49.33253751*C+4462.000387*C**2
      RT2=1.304708284-17.137396*C+882.4607369*C**2
      RT3=1.279406888-79.94199075*C+13298.72526*C**2
     1-663906.1468*C**3
      RT4=1.295867563-8.334689436*C+388.0756072*C**2
      RT5=1.300994696-35.63547499*C+5915.885313*C**2
     1-308163.9222*C**3
      GO TO 35
15    RTMB=1.0
```

```
      GO TO 30
20    RT1=0.7639026905+51.08937985*C-7920.581378*C**2
     1+407496.8278*C**3
      RT2=0.7449498217-55.91887372*C+11590.43566*C**2
     1-619289.3859*C**3
      RT3=0.7478987996-36.11489217*C+6590.878348*C**2
     1-323348.1681*C**3
      RT4=0.7540579051-22.48224933*C+4397.834059*C**2
     1-213836*C**3
      RT5=0.7351567674+4.047577695*C-232.2425808*C**2
      GO TO 35
25    RT1=0.653658692 4+63.54014267*C-9351.163969*C**2
     1+471203.0296*C**3
      RT2=0.6128202321-76.66470325*C+15137.91641*C**2
     1-771889.1592*C**3
      RT3=0.6284534151-68.49645331*C+12799.12036*C**2
     1-656891.3365*C**3
      RT4=0.6259496202-22.52213653*C+4546.007189*C**2
     1-231288.7587*C**3
      RT5=0.6003899964+8.569140736*C-949.977975*C**2
     1+36220.92632*C**3
      GO TO 35
30    CONTINUE
      RETURN
      END
      FINISH
```