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STUDIES OF SMALL PARTICLE SUSPENSIONS FOR L.M.F.R.

PART IV

CONCENTRATION GRADIENTS IN FLOWING SUSPENSIONS

by

R. C. CAIRNS
K. R. LAWTHER

Sydney, July, 1958.

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Abstract

A radiometric method and the apparatus used to measure concentration gradients in flowing suspensions are described. Both iridium 192 and thulium 170 sources have been used to measure gradients.

Traverses of both a horizontal and a vertical pipe, in which a tungsten–water suspension was flowing, have been made. Plots are given for various velocities, of the concentration distribution in percent tungsten by weight across the pipe at right angles to the direction of flow.

Very turbulent conditions, with velocities in excess of 13.4 feet per second (Re > 161,000) in a 1–in. square pipe, are needed before uniform suspension would be achieved. At 13.4 feet per second, the difference in concentration from top to bottom of the pipe amounts to approximately 6 percent of the bottom concentration. Much larger concentration gradients exist at lower velocities.

In vertical flow no measurable concentration gradients exist for mean velocities of 2.6 to 6.3 feet per second, (Reynolds number 29,000 to 74,000) in a 1–in. square pipe.

Striations noticed in previous work near the settling point were again observed in this work.

CONTENTS

1. INTRODUCTION

It has been proposed that a suspension of finely divided uranium particles in liquid sodium is likely to be a suitable suspension for L.M.F.R.

For experimental study of suspension stability, a suspension of tungsten metal powder in water has been chosen to simulate the U–Na system because of the similarity in effective densities, i.e., difference in density between solid and liquid, and because the viscosities of the liquid media are comparable. Also tungsten metal powder is readily available in sub-sieve sizes, the particle size envisaged for the uranium being approximately 10 microns.

Work has already been reported (2) for tungsten suspensions, on the friction losses, settling properties, and velocities required to maintain the powder in suspension in a horizontal pipe. Additional data (3) have been obtained for the $BaSO_4$–H_2O system, which simulates the UBe_{13}–Na system. A correlation of horizontal settling velocities (1) has been attempted in terms of the effective density ratio, defined as the ratio of the difference between the solid and liquid densities to the density of the liquid.

Thompson (5) has analysed a simplified model of a U–Na–Be circulating fuel reactor to determine the root mean square power and temperature fluctuations due to random variations in the inlet fuel concentration. Although the results apply only to the particular system studied under one set of operating conditions, they indicate that limits of ± 2 percent on the fuel concentration, averaged over a channel, should reduce the mean power excursion, due to this cause, to less than ½ percent.

Concentration, as defined by Thompson, is the number of atoms of fissile material per unit volume of suspension. The analysis is independent of the concentration distribution across a given cross section of a vertical tube in the core, as the treatment is confined to fluctuations in concentration from the time averaged concentration at a point.

Reactor stability will be influenced by both fluctuations in concentration at a point in a tube of the core, as well as changes in the concentration distribution across each of the core tubes. Stability will be affected also by sudden concentration changes in fuel fed to the core tubes.

This report deals with concentration distributions or gradients across a horizontal pipe and a vertical pipe as the mean velocity is varied. It has yet to be shown quantitatively what change in concentration of fissionable material fed to the core is tolerable. The measurements reported here are given to indicate the concentration variations that do exist in typical suspensions in horizontal and vertical flow, and so add to the understanding of the behaviour of suspensions. It is important to remember in this work that the dimensions and configuration of the L.M.F.R. core and headers have not yet been defined. Considerably more effort would be needed to measure experimentally instantaneous fluctuations at a point and it was not the intention to do this.

Concentration gradients are defined here as the rate of change of concentration with distance across a section perpendicular to the direction of flow. There has been no data previously published on this problem for suspensions with particles of high effective density and small size.

A radiometric method was used to measure the concentration distributions and, to facilitate concentration measurements, the tungsten suspension was pumped through a pipe of square cross section. A square pipe was adopted to avoid corrections necessary for a circular pipe, due to the changes in thickness of suspension and pipe wall. Also observation of the flow pattern in a square was needed to provide further information on striations reported in circular tubes, (2), (3).

2. EXPERIMENTAL APPARATUS

(a) Suspension Loop

The general arrangement of the loop, which was referred to as Suspension Loop Mark III, is shown in Figure 1.

The main tank was a stainless steel 45-gallon drum with side outlet near the base. The pump was an Ajax CKH 1 centrifugal pump with a 1-inch outlet capable of delivering 30 GPM against a head of 75 feet. Two lengths of square Perspex pipe of 1-in. x 1-in. internal section were used. These were made of Perspex strips ¼-in. thick, with bonding cement applied externally only, to keep the internal walls smooth and clean.

The loop was originally set up with connected quick-acting diaphragm valves so that a single arm movement would divert the flow into a calibrated measuring tank. However, it was found that with long periods between discharges, a settled bed built up in the closed valve causing a blockage when the valves were operated. A flexible pipe was arranged in place of the valves to permit flow diversion to a stainless steel weighing vessel.

Considerable difficulty was experienced in obtaining sufficient agitation in the main tank to maintain complete suspension of the powder and yet prevent entrainment of air bubbles. Two 1 HP, 1400 RPM stirrers were used and after trying a number of different types, sizes and combinations of impellers, it was found that two propellor-type agitators could be used to give satisfactory agitation, assisted by the by-pass discharge.

The tungsten powder used was the 2 micron grade by microscopic count supplied by B.H.P. Co. Ltd., Newcastle, Australia. The particle size analysis as determined by the Andreasen pipette, which involves sedimentation in water, is given in Table I. Spectrographic analysis of samples of the powder before use showed trace quantities or less of Mo, Fe, Ti, Cr, Ca, Ni, Co and V. The elements Mg, Al, Mn, Zr and Cu were not detected.

(b) Concentration Gauge

The radiometric technique was used to measure the concentration of tungsten in suspension across a plane at right-angles to the direction of flow through the square pipe. Figure 2 shows the general arrangement of the traversing equipment.

A gamma emitting source in a lead bomb was set up on one side of the square pipe. The gamma beam passed through the Perspex square pipe containing the flowing suspension, and was then collimated through a 1/16-in. hole in a 2-in. thick lead block on the other side of the square pipe before being detected by a sodium iodide crystal and scintillation counter.

The number of counts shown on the scaler in a given time is proportional to the intensity of gamma radiation incident on the crystal. This depends on the average tungsten concentration of the suspension at the position through which the radiation passed prior to passing through the 1/16-in. collimating hole.

The whole arrangement, including lead source holder, collimating block and scintillation head was mounted on a table attached to one of a pair of movable wedges. This table could be moved at right-angles to the pipe by means of a handwheel operating a screw which moved the wedges so that the gamma beam traversed the square pipe at known distance from the bottom of the pipe. The beam could be moved right across the pipe and clear of it by means of the handwheel. A reference scale on the base was calibrated to indicate the vertical displacement. Figure 3 is a view of the equipment set up for the horizontal pipe traverse.

The internal dimensions of the pipe in the region through which the gamma beam passed were measured by the Metrology Division of C.S.I.R.O. National Standards Laboratory, Chippendale, Sydney, using an air gauge technique developed by that laboratory. The widths of the pipe in inches at the traversing plane as measured from the inner top horizontal surface of the pipe for a temperature of 68° F were as follows:-

0.25 inch from top	0.5 inch from top	0.75 inch from top
1.001	0.999	0.996

The accuracy associated with these measurements was ± 0.001 inch.

In the traverse of the horizontal pipe an upstream calming length of 100 equivalent diameters was used with a downstream length of 20 equivalent diameters. The upstream length was broken only by a matched flanged joint with a 0.010 in. thick P.V.C. gasket at an upstream distance of 36 equivalent diameters. The gasket hole was identical to the internal section of the pipe. The flange was used to join the maximum lengths of square pipe available. In the traverse of the vertical pipe, an upstream calming length of 36 equivalent diameters was used with a downstream calming length of 20 equivalent diameters. The upstream calming section was preceded by a 90° elbow of 1-in. square cross section and a 5 ft. 4 in. length of horizontal square pipe.

For the first runs the gamma source was iridium 192, of approximate activity 125 millicuries, obtained by the Isotopes Section of A.A.E.C. from A.E.R.E., Harwell, U.K. Iridium 192 is suitable for measurement of high tungsten concentrations because of the high energy gamma rays in its spectrum (6). For low concentrations in the 1-in. Perspex pipe, thulium 170 is more suitable because it is a source of low energy gamma rays (6).

As the theoretical concentration of tungsten is only 7.9 percent by weight for simulation of the 1 to 100 atomic ratio of uranium to sodium, proposed for L.M.F.R., thulium 170 was needed for determining concentration gradients in fully suspended flow. This source was obtained by the Isotopes Section of A.A.E.C. from the Nuclear Research Corporation, Southampton, Pennsylvania, U.S.A., with an activity specified as 750 gamma millicuries at 6th January, 1958. It was supplied in a magnetic stainless steel capsule, and a small permanent magnet was fitted to the insertion piece in the source holder to hold it in place.

The calibration of the concentration gauge using iridium 192 and thulium 170 has been previously reported (6).

(c) Method of Making a Run

The horizontal pipe was traversed first since the iridium 192 source was available and it was suitable for measurement of the higher concentrations in beds during the settling condition.

Thulium 170 was used for the traverses as soon as it became available from U.S.A. (Supply of a thulium source from U.K. was prevented by the Windscale accident). It was used first on the horizontal pipe for the fully suspended flow condition, and then for the vertical pipe traverses.

(i) Horizontal Pipe

The loop was assembled and filled with demineralised water. This was pumped through the loop to leak test it before adding the tungsten powder. Tungsten was added to make a suspension of approximately 7.9 percent by weight and this was circulated to achieve a uniform suspension. After adjusting the flow rate by means of the loop and by-pass valves, the temperature was noted and the flow rate determined by weighing the discharge obtained in the weighing vessel in a known time. The discharge was replaced and after five minutes a traverse was started across the pipe, and a sample taken from the loop discharge to determine the approximate concentration of suspended solids. Counts obtained in 100 seconds, as timed by a stopwatch, were recorded at increments of 1/32-in. from the bottom of the pipe, and regularly at a position clear of the top of the pipe to serve as a reference count. After the series of readings another sample was taken from the discharge, the loop temperature again noted, and the flow rate re-determined. Also, during a run, samples were taken of the discharge as required to determine the mean concentration circulating. Samples were taken to analyse for dissolved tungsten present during the runs.

(ii) Vertical Pipe

The position of the vertical leg used on the loop is indicated on Figure 1.

For traverses of the vertical pipe, the adjustable table had to be set up vertically which necessitated the use of a number of strong springs to hold the sliding wedges together. The procedure used in this case was identical to that for the horizontal pipe. Vertical pipe traverses were not made below velocities at which heavy beds deposited in horizontal sections.

3. METHOD OF EVALUATING DATA

(a) Effective Dead Time Correction

Count rates obtained on the scintillation counter assembly were corrected for paralysis or effective dead time. The corrected count rate is directly proportional to the intensity of collimated gamma radiation, I, incident on the detecting crystal, and is equal to $\frac{N}{1 - N\tau}$ (8). The relative count rate then is:-

$$\frac{I}{I_A} = \frac{N}{N_A} \cdot \frac{(1 - N_A\tau)}{(1 - N\tau)}$$

The value of N_A used in this equation was the mean of the reference counts in air before and after each set of readings of N. The values of τ determined by the Isotopes Section of A.A.E.C., using a method involving variation of the time interval between pulses fed into the counting equipment, were 5.4×10^{-6} second for runs 3-7 inclusive and 1.4×10^{-6} second for runs 11-13 inclusive. These values correspond to two different settings of the paralysis time on the scaler.

(b) Calibration Data

The iridium 192 and thulium 170 gamma sources were accurately calibrated (6) so that the counting rate could be related to the amount of tungsten in the suspension. The calibration data were plotted in reference (6) in terms of the ratio I/I_o corresponding to grams of tungsten per c.c. of suspension, where I/I_o is the ratio of the count rate through the pipe of tungsten suspension to the count rate through the pipe filled with demineralised water only.

For the present set of experiments original tabulated calibration data were used (7), and these are given in Table II. Also, it was more convenient to have the calibration in terms of the relative count rate I/I_A where,

$$I/I_A = (I/I_o) \times (I_o/I_A)$$

corresponding to weight percent tungsten in the suspension. Values of the ratio I_o/I_A for iridium 192 and thulium 170 were determined with the pipe filled with demineralised water. These results are given in Table III. Using the mean value of I_o/I_A corresponding values of I/I_A and tungsten concentration were evaluated. These are given in Table IV and Figures 4 and 5.

(c) Variations in Internal Pipe Dimension

At the position of traversing, the results can be influenced by change in thickness of the suspension because of variations in the width of the pipe. This is important for the thulium 170 runs.

As the width of the pipe was measured at three positions, as outlined in 2b, and found to vary only −0.003 inch +0.002 inch from the centre reading of 0.999 inch, no correction was necessary as this corresponds in the thulium runs to less than 1 percent correction to the relative counting rate.

4. RESULTS

(a) Horizontal Pipe

(i) Iridium 192

Results were obtained for a number of runs with mean loop velocities from 0.7 to 9.3 feet per second.

Before settling, striations were evident along the floor of the pipe. These are shown in Figure 6 which is a view from below the pipe. As the velocity was reduced below the horizontal settling velocity of approximately 3 feet per second, islands moving in the direction of the flow were formed on the floor of the pipe. These merged at lower velocities to become moving dunes which finally became stationary at very low velocities. Figures 7 and 8 are views of the moving islands from below the pipe, and dunes from the side of the pipe, respectively.

Figure 9 shows the results of the radiometric traverse with iridium 192 for various loop velocities. The relative count rate was evaluated from the ratio of the actual count rate with the suspension to the mean count rate for air obtained from counts before and after each group of readings. This ratio was then corrected for dead time. The counts for air were obtained by winding the table up so that the beam passed through air only.

During the pumping experiments, the mean velocity slowly decreased once a bed had formed. The velocities shown in Figure 9 correspond to two flow rates measured usually before and after each traverse. On occasions the dunes which formed at certain critical velocities slowly moved along the bottom of the pipe and into and out of the beam. For one run shown in Figure 9 (run 5.2), flow was suddenly reduced to form an even bed, which it was otherwise not possible to produce.

No definite striations were visible at the vertical walls of the square pipe, but lines much less pronounced could be seen with difficulty during and just before settling. Striations were not evident above 6.5 feet per second. Almost constant readings for the traverses with iridium 192 were achieved above 6.5 feet per second.

The concentration of dissolved tungsten present in the water before and after these experiments was less than 0.2 percent.

(ii) Thulium 170

In general traverses were taken across the pipe and back for each flow setting to ensure the concentration was not changing with time. Runs in which concentration did change with time were rejected.

Figures 10a to 10e show the results for the thulium 170 traverse on the horizontal pipe. Figure 5 was used to convert the readings from relative count rate to percent tungsten by weight.

As the presence of dissolved tungsten is more critical for the runs with thulium 170, this was determined by analysis before and after each set of runs. The concentration of tungsten present in solution was less than 0.1 percent for these experiments. As this, in the worst case, corresponded to less than 2 percent of the total suspended tungsten it was not considered to be significant. Furthermore, for one set of traverse readings, the small correction due to dissolved tungsten is effectively constant for fully suspended flow, and would involve only a constant reduction of less than 0.1 percent from the percent suspended solids for all points, having no effect on the concentration gradient.

(b) Vertical Pipe with Thulium 170

Figure 11 shows the results for these runs as percent tungsten versus distance from one side of the pipe. The dissolved tungsten was again less than 0.1 percent. Traverses were taken across the pipe and back for each flow setting.

5. DISCUSSION

(a) Horizontal Pipe

(i) Iridium 192

It can be seen from Figure 9 that below the settling velocity, beds of islands or dunes are formed, and these are quite dense. The relative count rates in the beds for runs 5.2 and 5.5 correspond to a concentration of approximately 92 percent by weight or a bulk density of 8 g/cc. This is high compared to the average bulk density of 4.6 g/cc or 83 percent tungsten obtained by gravity sedimentation on the same powder. This may be due to the fact that gravity sedimentation involves a classifying action, in that the large particles settle first and the finer particles settle on the larger particles; whereas deposition of particles from a flowing suspension in a pipe produces a bed in which small and large particles are mixed. The shearing action of the bed as it moves in a pipe as well as system vibration caused by the pumping action are other factors contributing to a high bed density.

The results plotted in Figure 9 show that the minimum mean velocity required to prevent settling of the powder in the horizontal square pipe is between 2.6 and 3.0 feet per second. This agrees with previous observations of 2.5 to 2.9 feet per second for a circular 1-in. i.d. horizontal pipe (2).

Definite concentration gradients were evident in the suspension in the fully suspended state, but at velocities above 6.5 feet per second, the readings were almost constant. These iridium traverses showed that velocities higher than 6.5 feet per second are required for a uniform concentration.

The concentration gradients, cannot be evaluated since iridium 192 is not suitable for measurements of such low concentrations of tungsten, and no attempt was made to calibrate it for these concentrations. It is interesting to note that the readings taken on the suspension above a settled bed (runs 5.2 and 5.5) did not have such a gradient.

(ii) Thulium 170

With increasing velocity it is to be expected that the suspension would be more uniform, and this is shown by the increasing negative slopes in Figures 10a to 10e where the mean velocity varies from 3.2 to 13.4 feet per second. Using the density and viscosity (4) of the suspension the mean Reynolds numbers for these runs varied from 31,000 to 161,000.

It is surprising that the very turbulent conditions existing, particularly in run 12.2 where the mean Reynolds number is 161,000, did not give uniform mixing of the suspension. The negative slope in Figure 10e corresponds to a decrease of approximately 0.5 percent w/w in the suspended tungsten present from the bottom to the top of the pipe. This is equivalent to a change of approximately 6 percent in the concentration of tungsten across the pipe section.

Plotting the slopes from Figures 10a to 10e versus velocity on semi-log paper, as in Figure 12, indicates that velocities very much greater than 13.4 feet per second (Re > 161,000) are needed to produce a uniform suspension in horizontal flow. This is further evidence that the minimum Reynolds number of 2,000 – 3,000 accepted by other workers for "homogeneous" transport of sub-sieve sized particles in horizontal flow is incorrect. It was not possible with the present apparatus to determine the velocity at which complete uniformity of suspension is obtained.

The use of the radiometric technique assumes that during measurement the concentration across the pipe in line with the beam is constant. If very turbulent conditions with Reynolds numbers greater than 161,000 are needed to produce a truly uniform suspension, fluctuations in the mean concentration across a given level in the pipe may occur at lower Reynolds numbers. This could be the reason for the small amount of scatter shown in the figures.

The deviation of the points in Figure 10a on the downward traverse is due to the decrease in velocity encountered during this run, 3.3 to 3.0 feet per second. At 3.0 feet per second, very heavy striations were evident and a bed had almost formed.

It was noticed that the results for the beam just above the bottom of the pipe were consistently high. This may be due to tungsten particles depositing in the internal crevices between adjacent walls of the Perspex pipe, causing a slight build-up of particles in the lower corners. Furthermore, readings close to the pipe walls at both the top and bottom of the pipe are less reliable because a small error in alignment causes part of the beam to travel through the perspex.

(iii) Striations

When the flow rate of a suspension was decreased from the fully suspended state, striations appeared on the bottom of the pipe as the horizontal settling velocity was approached. These striations which have been observed and described in previous work (2), (3) are longitudinal bands of higher particle concentration than the surrounding suspension. They were most noticeable at velocities just above the settling velocity, and were observed only on the base of the square pipe. Striations are apparently narrow moving beds with velocities much less than the main stream velocity. Turbulence in the main stream is sufficient to prevent an even bed forming although the explanation for line formation is unknown.

At the same time, "negative" striations were observed at the top of the pipe. These are longitudinal bands of lower particle concentration than the surrounding suspension. No striations were observed through the vertical walls, but lines much less pronounced were visible.

(b) Vertical Pipe with Thulium 170

Figure 11 shows that in vertical flow the suspension concentration is uniform across the cross section for mean bulk velocities from 2.6 to 6.3 feet per second. The lower concentrations obtained on the return runs in each case are attributed to loss of tungsten during the experiment, through the pump gland which at this stage was giving trouble. This was particularly noticeable at the high velocity, run 11.1, where considerable tungsten leakage from the pump occurred. Further attempts will be made to measure the concentration at the higher velocities.

The absence of concentration gradients across the square pipe for the vertical traverses confirms that gradients obtained for horizontal flow at these velocities must be due solely to the horizontal position of the pipe.

6. CONCLUSIONS

Concentration gradients have been measured for both horizontal and vertical flow.

For horizontal flow in the 1-in. square pipe, very turbulent conditions with mean velocities much greater than 13.4 feet per second (Reynolds numbers > 161,000) are needed to eventually produce a uniform suspension. At 13.4 feet per second the concentration at the top of the pipe is approximately 6 percent lower than that at the bottom. Much larger concentration gradients exist at lower velocities.

In vertical flow no measurable concentration gradients exist for mean velocities from 2.6 to 6.3 feet per second (Reynolds numbers from 29,000 to 74,000).

7. FURTHER WORK

It is intended that concentration gradients through a 1–in. x 1–in. 90° elbow be determined. This information may establish the region where uniform mixing occurs in changing direction from horizontal to vertical flow.

8. ACKNOWLEDGMENTS

Acknowledgments are due to Mr. R.B.Beer, Mr. E.J.Lee, Mr. E.G.Thurstan and Mr. K.S.Turner who assisted with the measurements, and to Mr. R.B.Beer who prepared the diagrams. Credit is due to Engineering Services Section who were able to make, in particular, the traversing table, mounting gear and the square pipes to rigid specifications, and to the Analytical Chemistry Services Group for all analytical work. The co–operation of the Isotopes Section, in particular Mr. J.S.Watt, is also gratefully acknowledged, as well as much helpful discussion with Mr. C.L.W.Berglin.

9. SYMBOLS USED

I = intensity of collimated gamma radiation incident on the scintillation detector; I_A = through air only.

I_o = through the Perspex pipe containing demineralised water.

N = number of counts registered per second on the scintillation counter unit;

N_A = through air only.

τ = paralysis or effective dead time of the scintillation counting equipment.

10. REFERENCES

1. Cairns, R.C., AAEC/E17, February, (1958).
2. Cairns, R.C., and Turner, K.S., AAEC/E5, August, (1957).
3. Cairns, R.C., and Turner, K.S., AAEC/E16, February, (1958).
4. Orr, C., and Dallavalle, J.R., Chem. Eng. Symp. Ser. No. 9, 29, (1954).
5. Thompson, J.J., AAEC/E30, (1956).
6. Watt, J.S., and Lawther, K.R., Paper presented at the Australian Atomic Energy Symposium, Sydney, June, (1958).
7. Watt, J.S., Private Communication.
8. Whitehouse, W.J., and Putman, J.L., "Radioactive Isotopes," Oxford, (1953), Clarendon Press

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TABLE I

PARTICLE SIZE ANALYSIS OF TUNGSTEN POWDER

Stokes Diameter Microns	Percentage Undersize by weight
16	50
15	41
10	18
5	4
4	2.5
3	1.5

TABLE II

ORIGINAL CALIBRATION DATA FOR IRIDIUM 192 AND THULIUM 170 (7)

	Tungsten Concentration g tungsten/c.c. suspension	I/I_o
Iridium 192	0.000	1.0000
	0.788	0.6152
	1.576	0.4061
	2.400	0.2714
	3.198	0.1913
	4.014	0.1371
	4.787	0.1038
	5.570	0.0799
	6.370	0.0624
	7.144	0.0500
	7.930	0.0408
	8.686	0.0347
Thulium 170	0.0000	1.0000
	0.0201	0.8357
	0.0401	0.7081
	0.0602	0.6052
	0.0802	0.5250
	0.1003	0.4608
	0.1204	0.4097
	0.1404	0.3676
	0.1605	0.3330
	0.1805	0.3052
	0.2006	0.2804

I/I_o = Relative count rate of scintillation detector for γ beam passing through tungsten suspension to that for γ beam passing through demineralised water.
(Absorber thickness for suspension = 0.999 inch.)

TABLE III

TRAVERSES ACROSS PIPE FILLED WITH DEMINERALISED WATER

Distance of beam C/L from bottom of pipe in 1/32 in.	No	N_A	$\frac{No}{N_A}$	$\frac{Io}{I_A}$
Iridium 192, $\tau = 5.4 \times 10^{-6}$ second.				
1	11420	16932	0.6745	0.6531
2	11429	16935	0.6749	0.6535
10	11432	16935	0.6751	0.6537
18	11438	16922	0.6759	0.6545
26	11415	16922	0.6746	0.6532
30	11395	16926	0.6732	0.6517
31	11389	16947	0.6720	0.6506
Mean				0.653
Thulium 170, $\tau = 1.4 \times 10^{-6}$ second.				
1	17472	31842	0.5487	0.5374
2	17457		0.5482	0.5369
3	17443		0.5478	0.5365
5	17452		0.5481	0.5368
7	17437		0.5476	0.5363
11	17436		0.5476	0.5363
15	17467		0.5485	0.5372
19	17448		0.5480	0.5367
23	17431		0.5474	0.5361
25	17440		0.5477	0.5364
26	17424		0.5472	0.5359
27	17413		0.5468	0.5355
28	17398		0.5464	0.5351
29	17383		0.5459	0.5346
30	17272		0.5424	0.5311
Mean				0.536

TABLE IV

CALIBRATION DATA FOR IRIDIUM 192 AND THULIUM 170

	I/I_A	Tungsten concentration % w/w
Iridium 192	0.653	0.0
	0.402	45.2
	0.265	63.2
	0.177	73.3
	0.125	79.4
	0.0895	83.6
	0.0678	86.5
	0.0522	88.7
	0.0407	90.5
	0.0327	91.9
	0.0266	93.1
	0.0227	94.1
Thulium 170	0.536	0.00
	0.448	1.98
	0.380	3.87
	0.324	5.71
	0.281	7.47
	0.247	9.19
	0.220	10.84
	0.197	12.4
	0.178	14.0
	0.164	15.4
	0.150	16.9

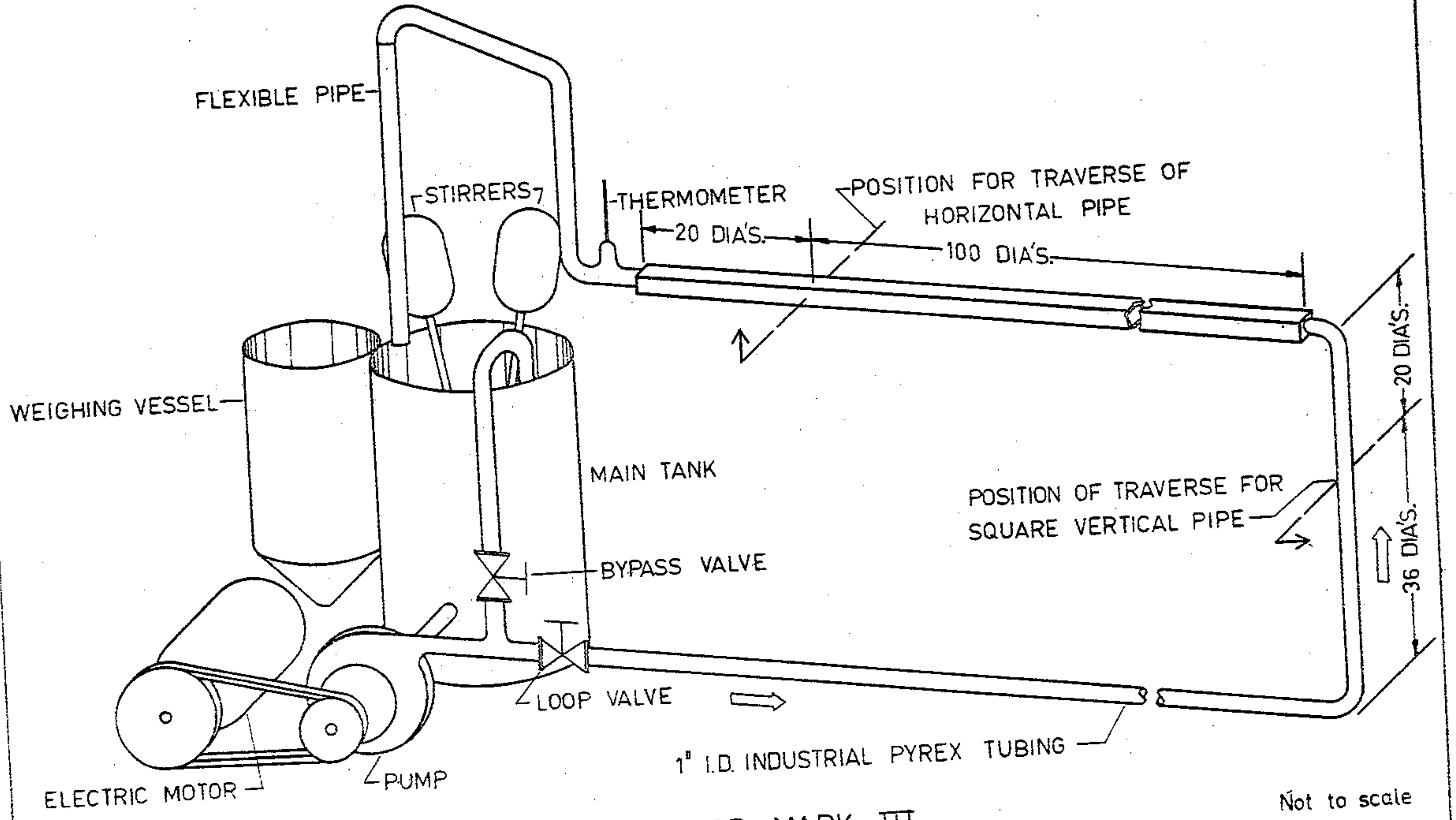

FIGURE 1. SUSPENSION LOOP MARK III

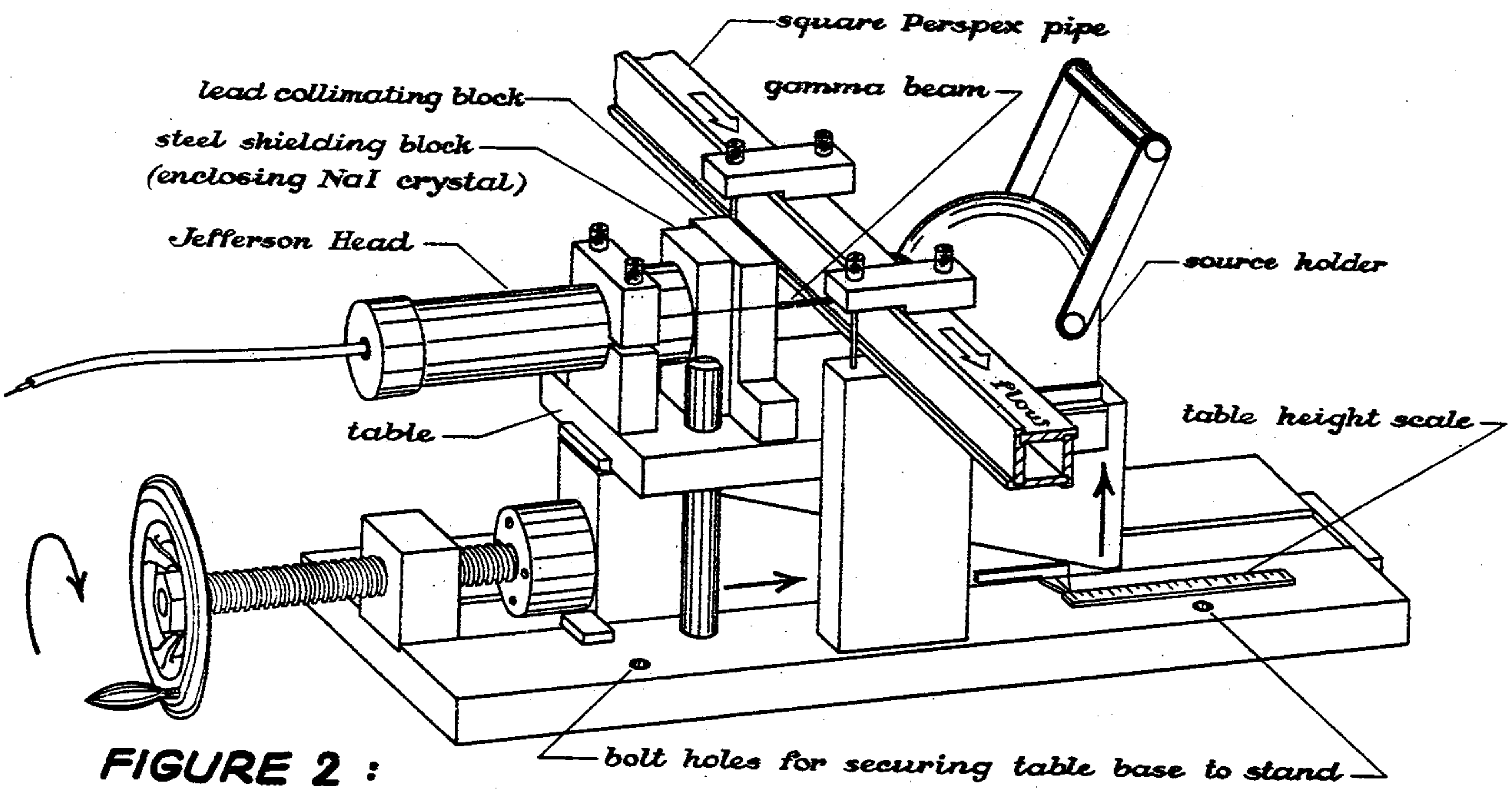

FIGURE 2 :

Adjustable Table for Radiometric Traverse of Pipe.

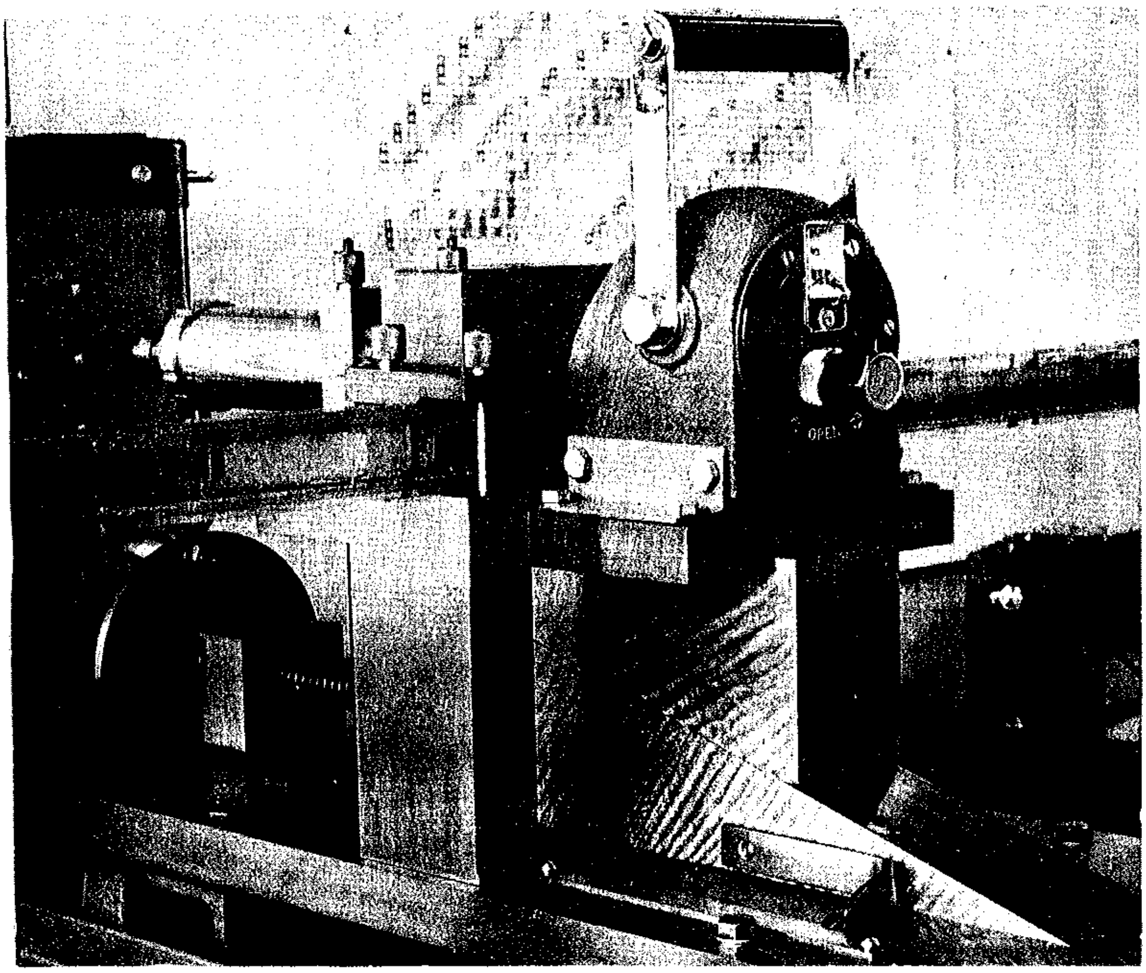

FIGURE 3 : View of equipment set up for the horizontal pipe traverse.

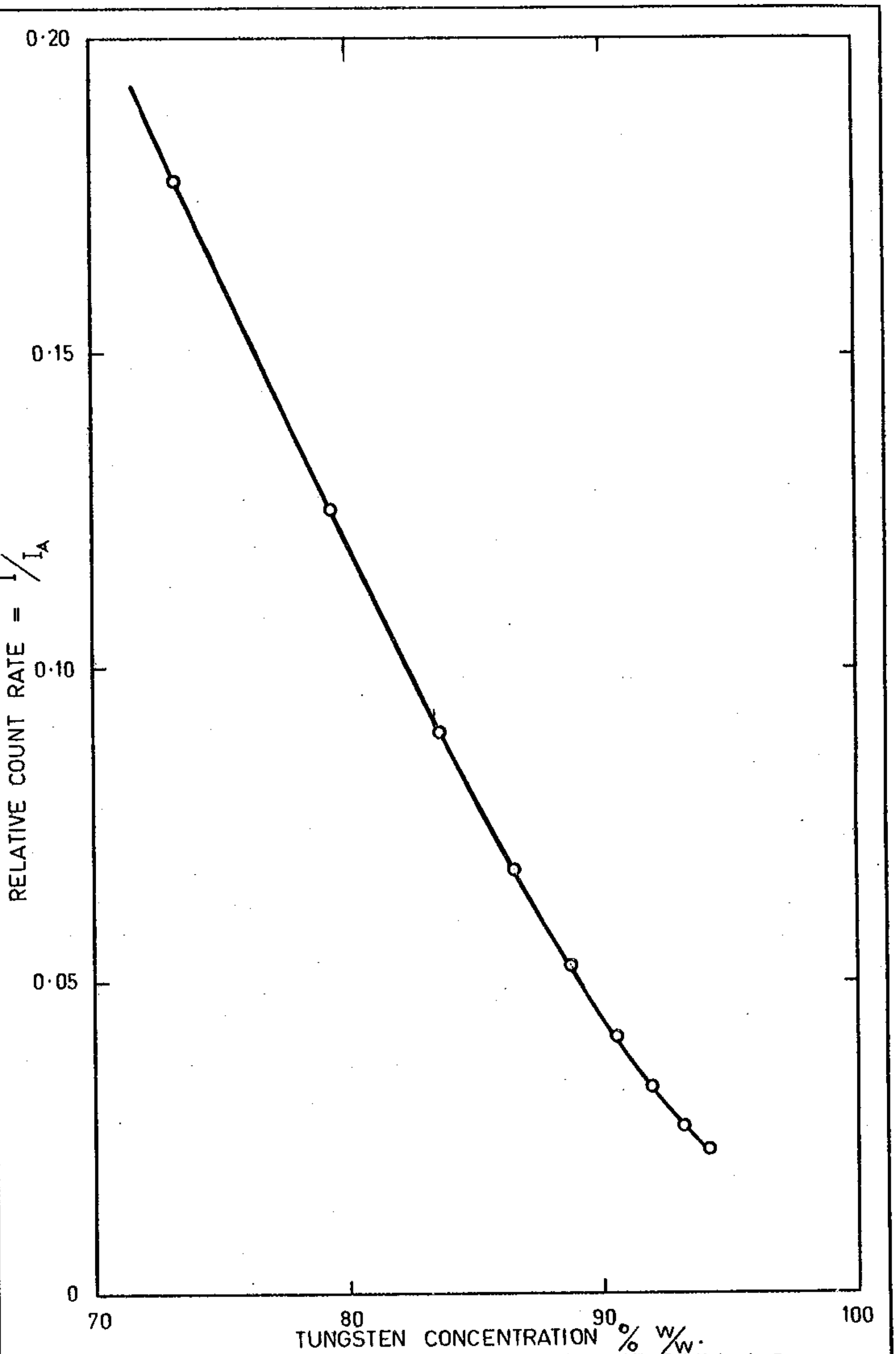

FIGURE 4: CALIBRATION CURVE FOR IRIDIUM 192

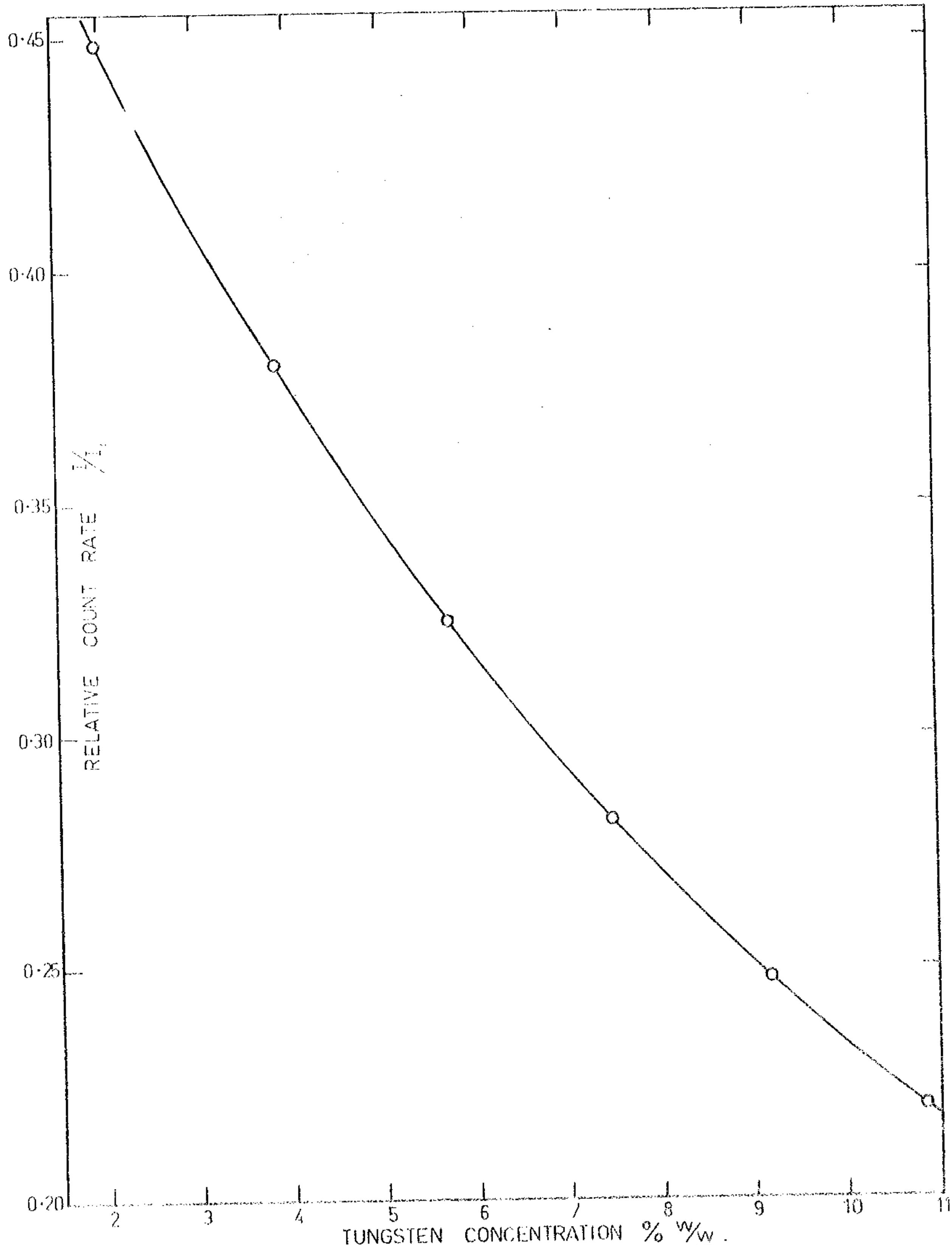

FIGURE 5: CALIBRATION CURVE FOR THULIUM 170

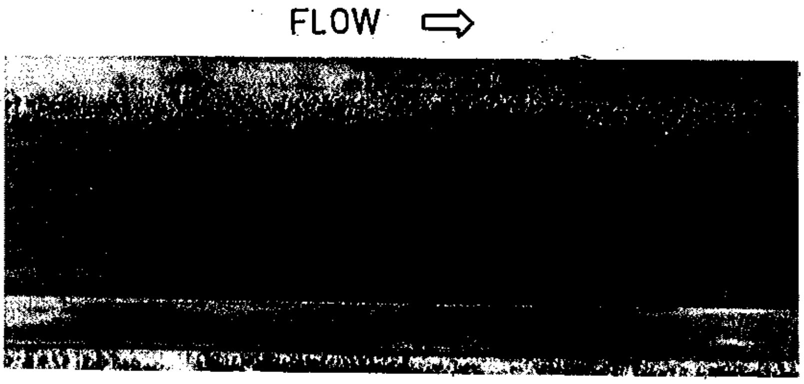

FIGURE 6. x1.

Striations present with 7·4 per cent tungsten suspension at 3·2 ft./sec.
View from underside of pipe.

FLOW ⇨

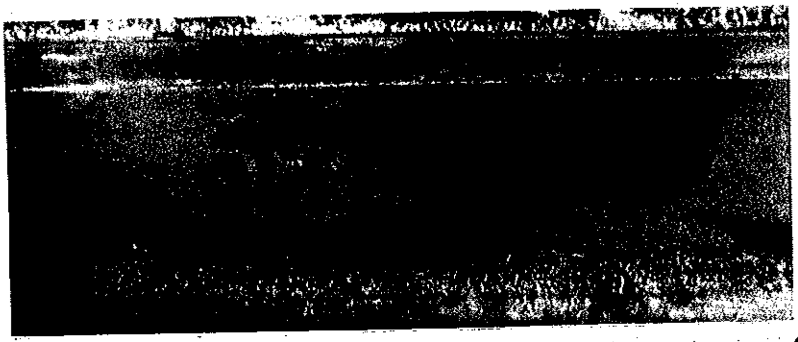

FIGURE 7.

x1.

Moving islands present with 7·4 per cent tungsten suspension at 2·6 ft./sec.
View from underside of pipe.

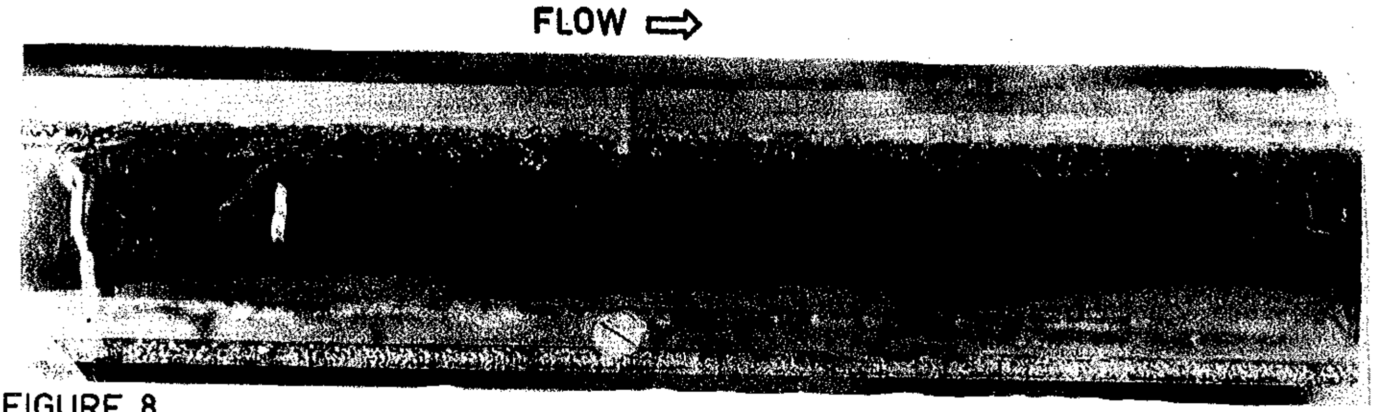

FIGURE 8.

Dunes present with 6·9 per cent tungsten suspension at 2·0 ft./sec. View from side of pipe.

x 1.

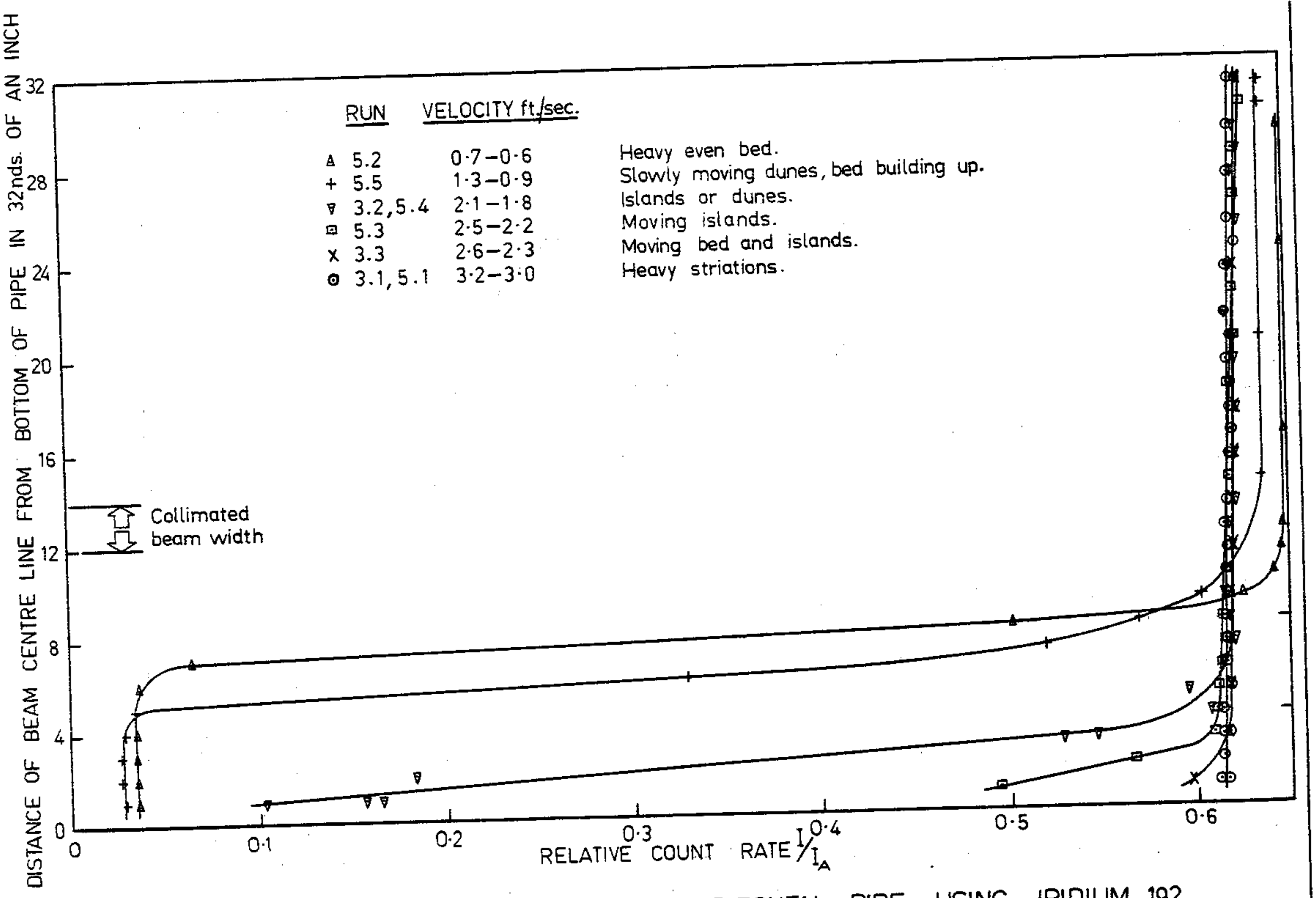

FIGURE 9 : RADIOMETRIC TRAVERSE OF HORIZONTAL PIPE USING IRIDIUM 192

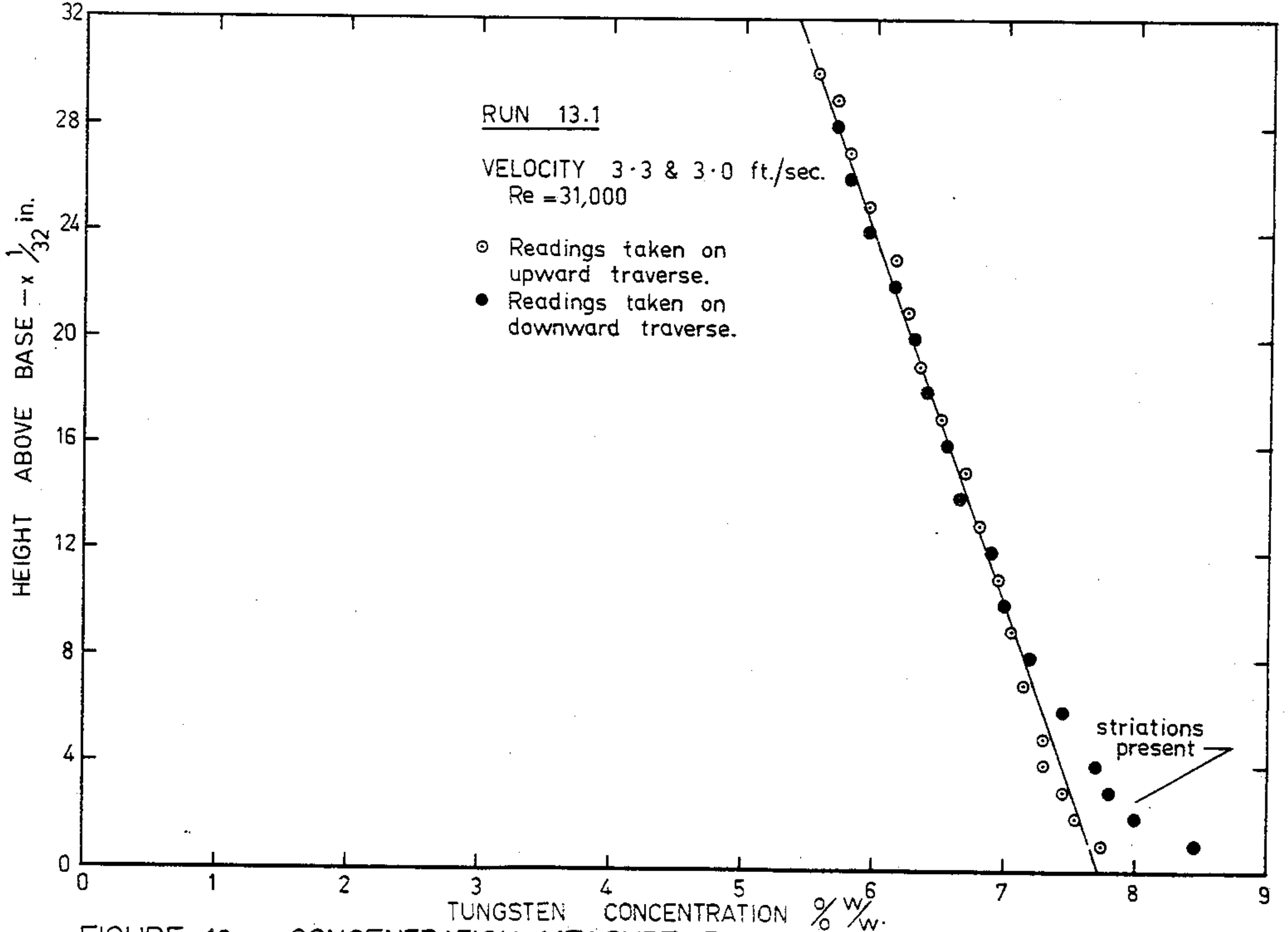

FIGURE 10a: CONCENTRATION MEASUREMENT ACROSS HORIZONTAL PIPE USING THULIUM 170.

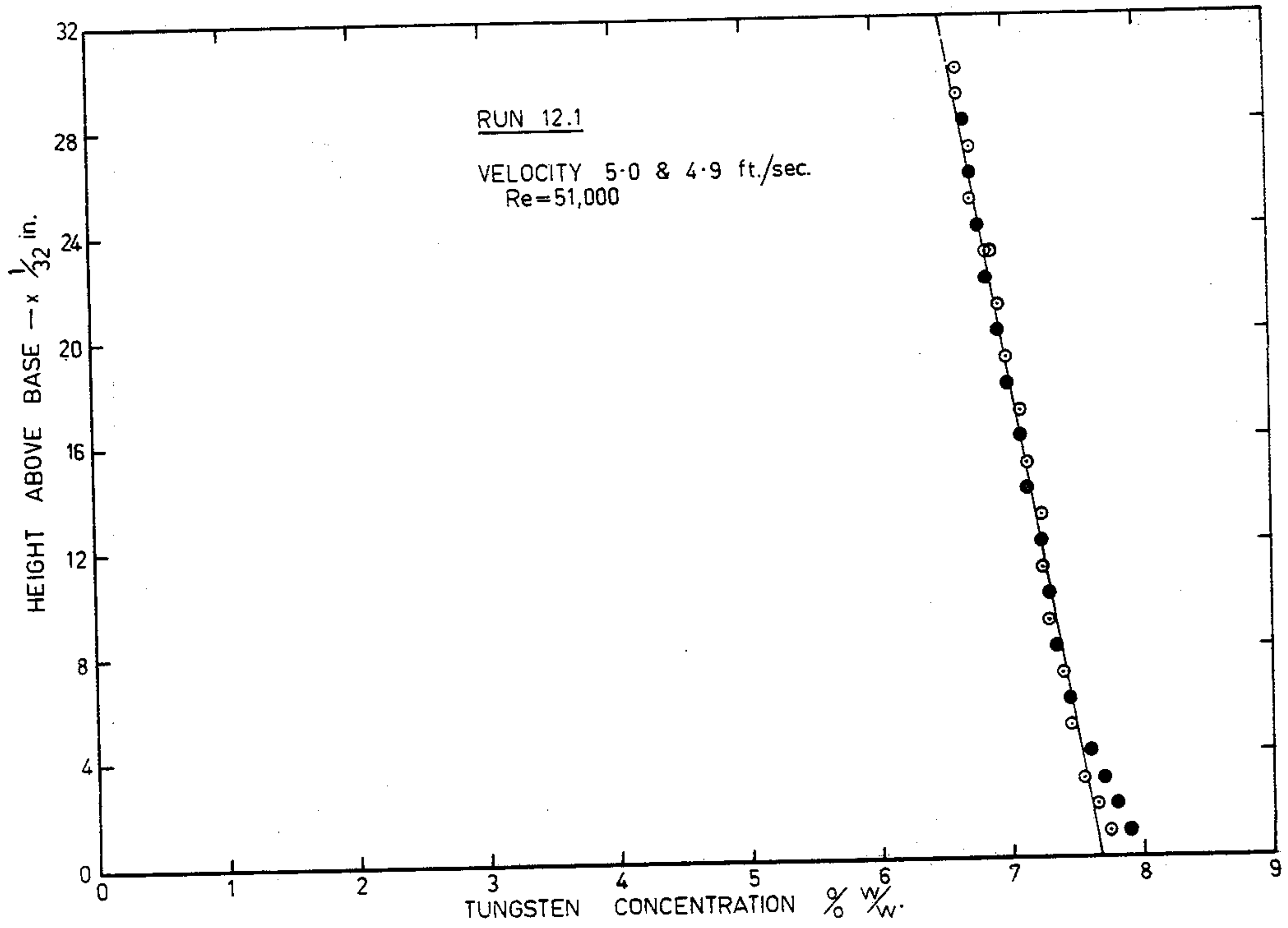
RUN 12.1
VELOCITY 5·0 & 4·9 ft./sec.
Re=51,000
HEIGHT ABOVE BASE — x 1/32 in.
0
4
8
12
16
20
24
28
32
0
1
2
3
4
5
6
7
8
9
TUNGSTEN CONCENTRATION % w/w.

FIGURE 10b:

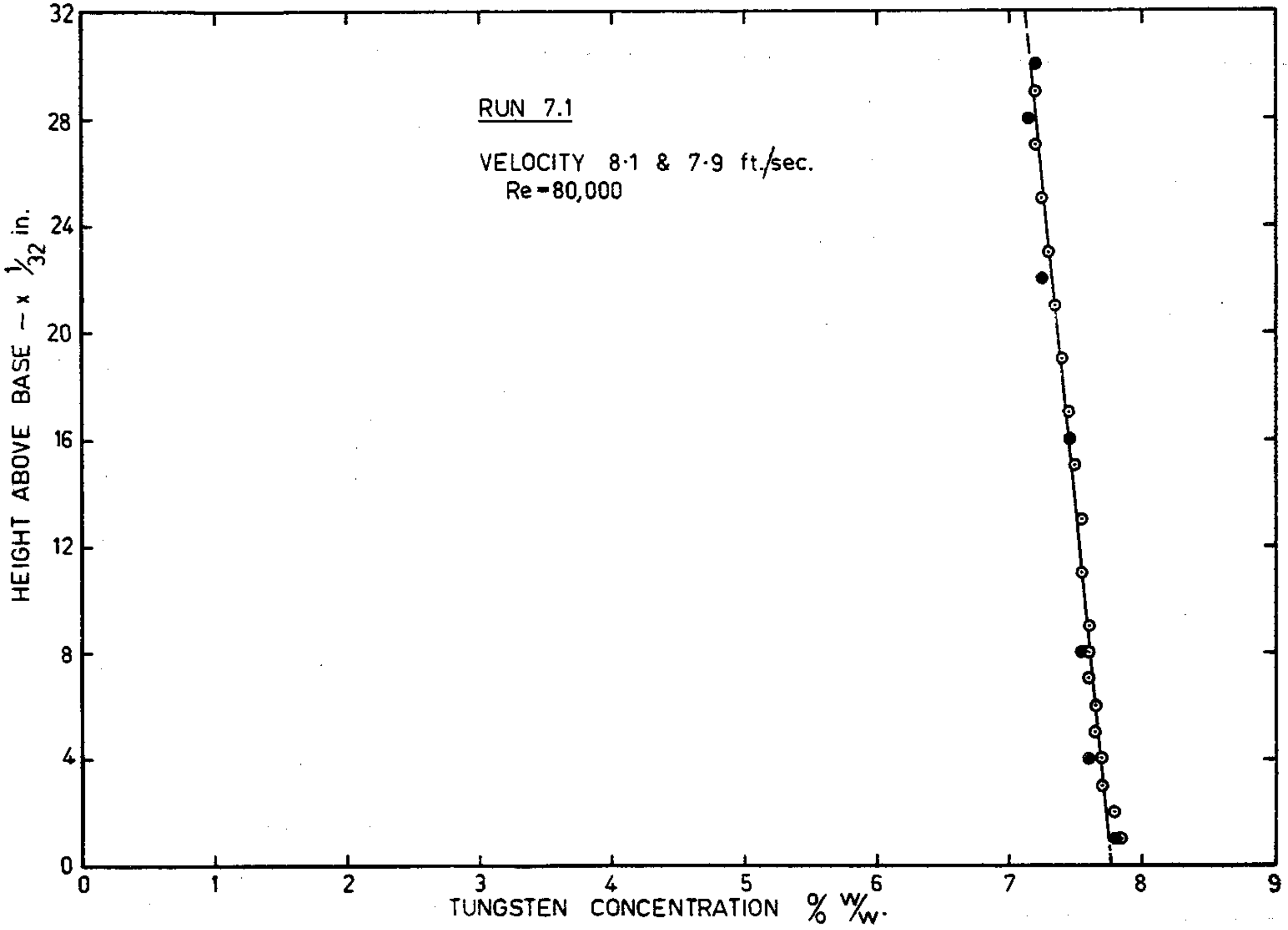
RUN 7.1
VELOCITY 8·1 & 7·9 ft./sec.
Re = 80,000
HEIGHT ABOVE BASE – x 1/32 in.
0
4
8
12
16
20
24
28
32
TUNGSTEN CONCENTRATION % w/w.
0
1
2
3
4
5
6
7
8
9

FIGURE 10c:

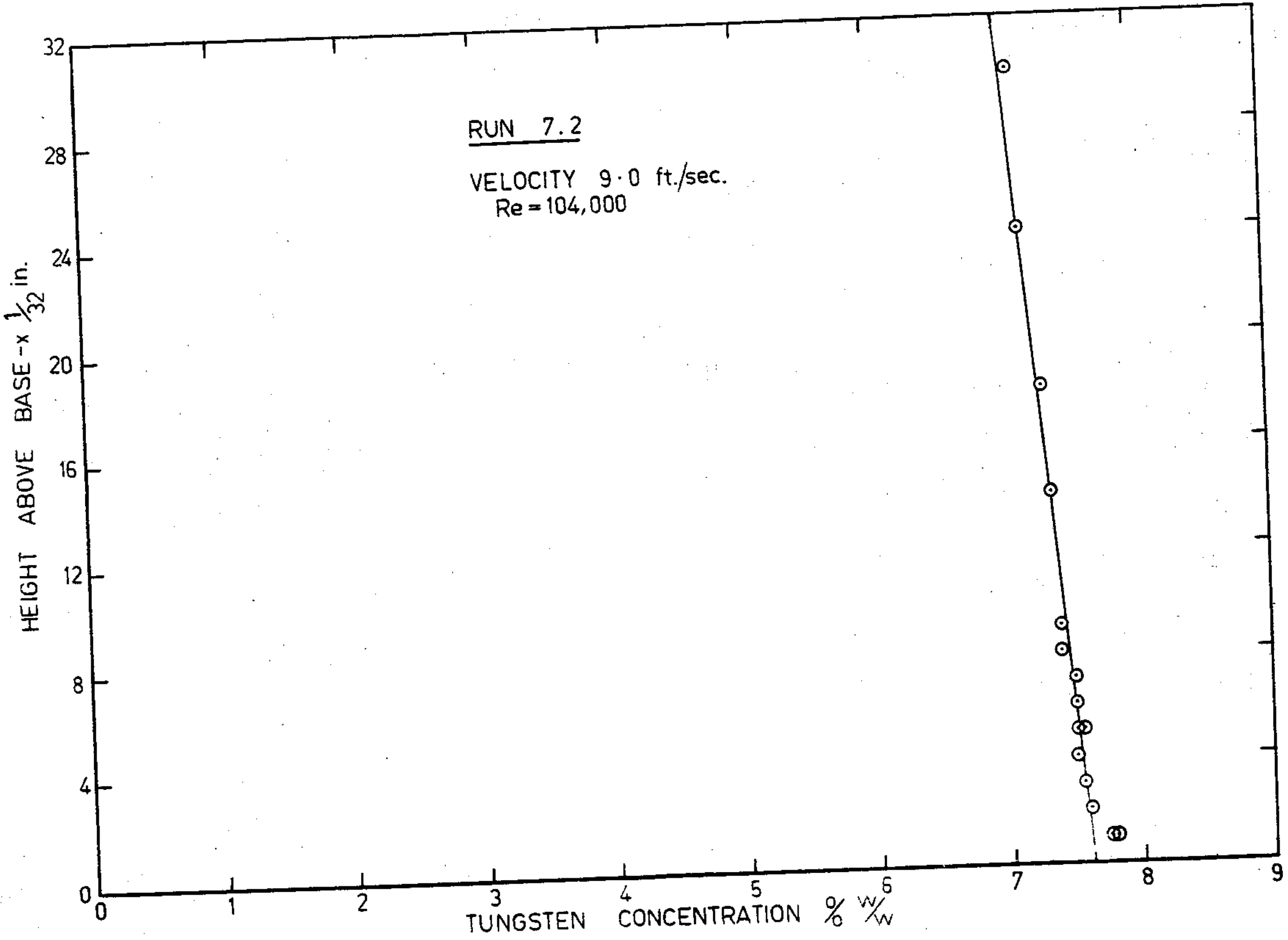
RUN 7.2
VELOCITY 9·0 ft./sec.
Re = 104,000
HEIGHT ABOVE BASE - x 1/32 in.
32
28
24
20
16
12
8
4
0
0
1
2
3
4
5
6
7
8
9
TUNGSTEN CONCENTRATION % w/w

FIGURE 10d:

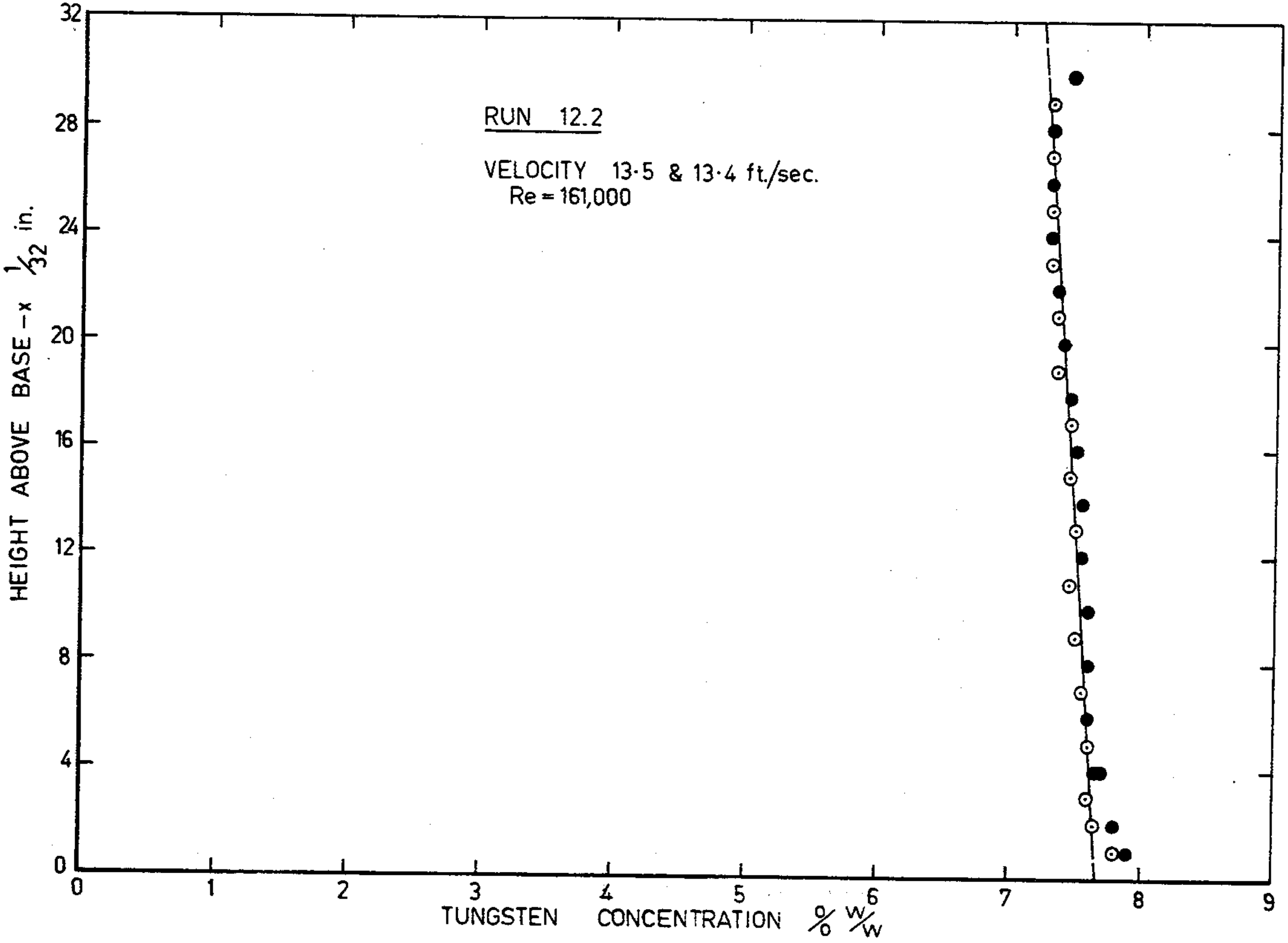
RUN 12.2
VELOCITY 13·5 & 13·4 ft./sec.
Re = 161,000
HEIGHT ABOVE BASE – x 1/32 in.
0
4
8
12
16
20
24
28
32
TUNGSTEN CONCENTRATION % w/w
0
1
2
3
4
5
6
7
8
9

FIGURE 10e:

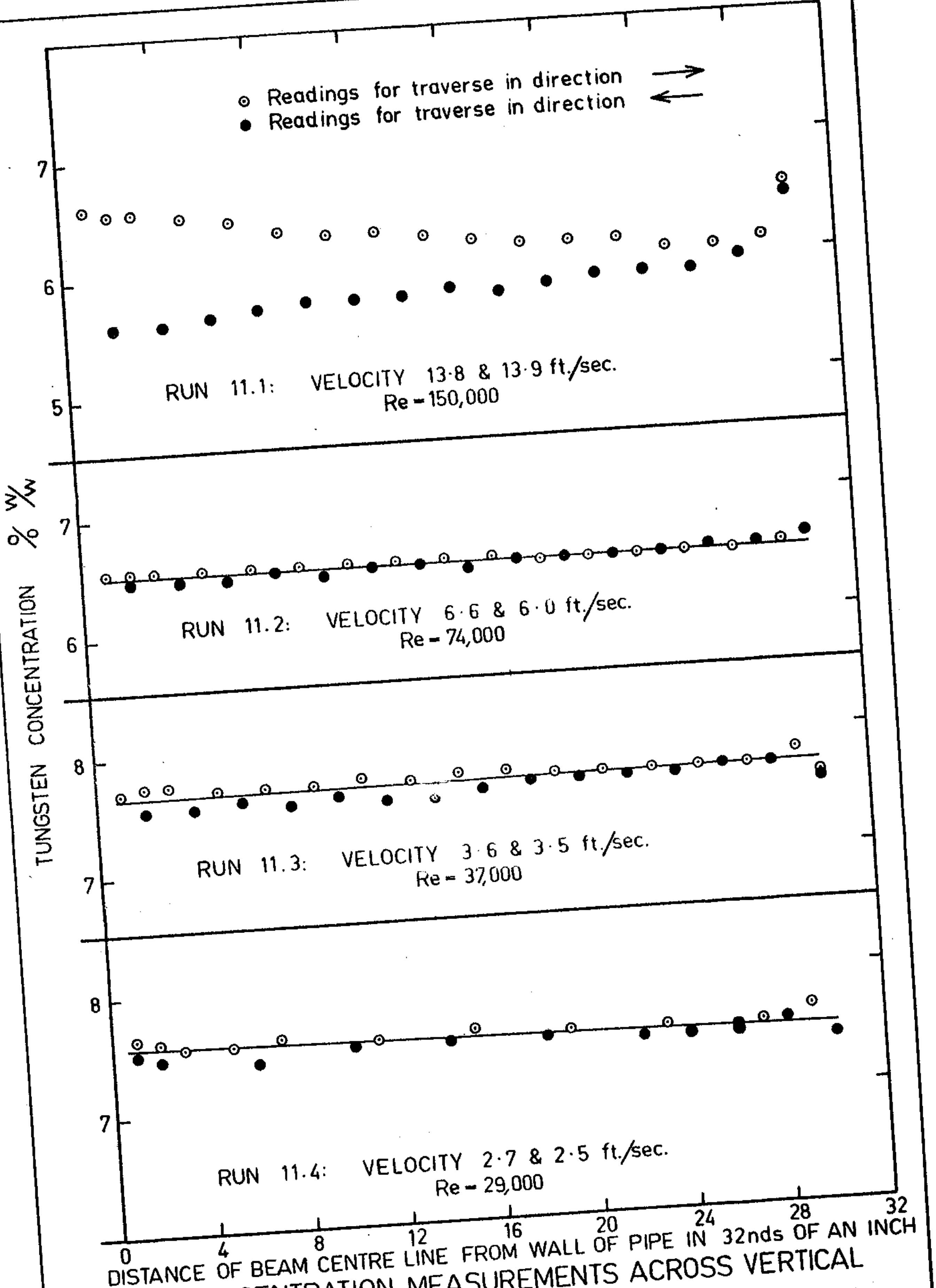

FIGURE 11: CONCENTRATION MEASUREMENTS ACROSS VERTICAL PIPE, USING THULIUM 170.

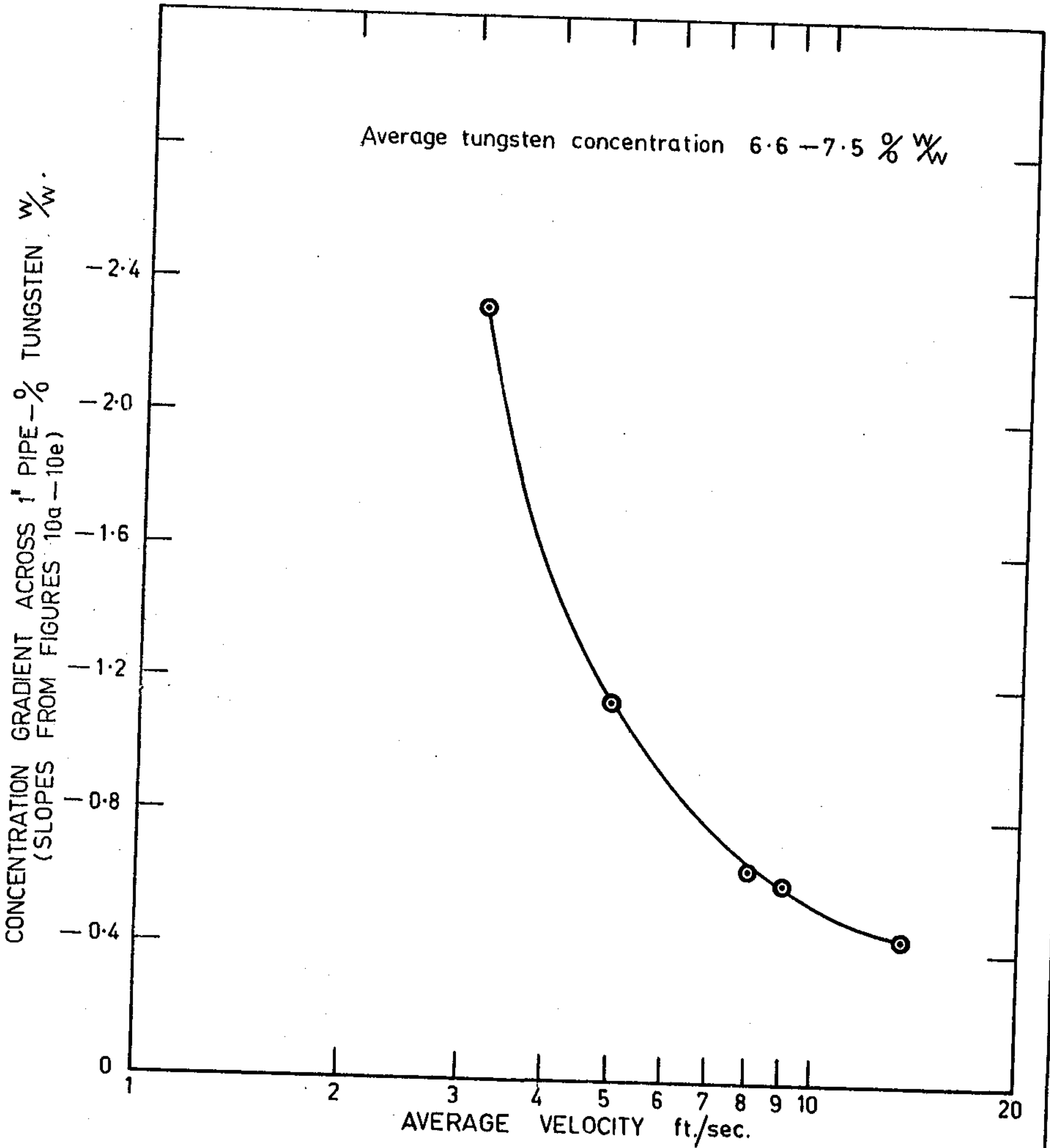

FIGURE 12: CONCENTRATION GRADIENTS IN HORIZONTAL PIPE.