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THE USE OF A RADIOACTIVE TRACER (IODINE 131) IN THE INVESTIGATION OF A POWER STATION COOLING POND AT MAITLAND N.S.W.

by

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SUMMARY

Radioactive iodine 131, as iodide in solution, was used to trace the flow of power station condenser water through a cooling pond. The station has a rating of 20MW and the circulating water is cooled in a pond of approximately 2 x 10^8 gallons capacity and 40 acres area. By labelling the warm water with 473 millicuries of iodine 131 in potassium iodide carrier, introduced at the power station outlet, and using underwater scintillation and Geiger counters, it was possible to follow quantitatively the horizontal and vertical spread of the water over a period of eight days after which mixing was complete. The results gave valuable information on the pond performance under the weather conditions prevailing during the test period and indicated some possibilities for improvement of performance. Further tests with iodine 131 are contemplated with modification of pond conditions.

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1. INTRODUCTION

The Electricity Commission of New South Wales is carrying out an extensive study of power station cooling ponds with a view to their possible use in projected large inland power stations on the Northern coalfields.

Experiments on cooling pond performance are being carried out at the 20 MW Maitland power station where an old reservoir of 195M. gallons maximum capacity with an area of 40 acres is used for cooling. The pond is in the shape of a Y with the warm condenser water entering at the top of one arm of the Y (north arm). The take-off point is at the base of the Y (east arm), (see Fig. 10). The take-off to the pump house is through a 30 in. diameter pipeline at a depth of five feet. During the period of the test described in this paper, the station was generating an output of 15 MW and the cooling water flow was at the rate of 14,500 gallons per minute. Fig. (1) shows a view of the pond from the power station.

One objective of these investigations is to obtain quantitative information regarding the rate of mixing and the flow patterns of the warm circulating water after it enters the pond, as these factors are vital to the prediction of pond performance.

Previously, tests had been carried out using fluorescein dye added to the warm water at the point of entry but this method is limited to observation of surface flow, is not quantitative in situ and under favourable conditions gives an indication for a maximum of only 5 to 6 hours.

Some preliminary calculations showed that a radio-tracer method, using a soluble radio-isotope with sensitive underwater γ scintillation crystal detection should give a much more extensive picture of the flow and mixing in the pond.

2. SELECTION OF SUITABLE RADIO-ISOTOPE

In the selection of equipment and radio-isotope for such a test, the following requirements must be met:-

(1) A gamma radiation emitter must be used to enable efficient underwater detection.

(2) The isotope used must have a half-life short enough to eliminate any residual radioactivity after the test but it should be long enough to permit completion of the test. A short half-life permits further tests to be carried out in the same system within a reasonable time.

(3) The isotope should be one with a safety tolerance high enough to permit quantitative detection at safe concentrations.

(4) The radio-isotope should be available in a water soluble form which is not readily adsorbed on the mud and weed of the pond.

(5) The question of cost and availability in Australia must also be considered.

Reference to previous work of a similar nature gave very little information on this subject, except that the use of iodine 131 is described in (1) for measurement of flow rates in pipelines and sewers. The same reference describes a flow-through test on a lake of 5.93M gallons with iodine 131. Twenty millicuries of iodine 131 was added at the inlet and samples periodically taken at the outlet. No attempt was made to follow the activity in the pond.

Bromine 82 has been used for studying the flow of underground water (2) and hold–up in sewage settling tanks (3). Phosphorus 32 has been used also for river flow study (4) and sea movement of sewage (5). However, bromine 82 has too short a half–life (36 hours) and phosphorus 32, being a pure β–radiation emitter, is difficult to detect under water.

For the various reasons given above, iodine 131 was chosen as the radio–tracer for this experiment. This radio–isotope has the following characteristics:–

Half life	8.04 days (6)
Energy of γ–radiation (MeV)	0.08 (2%) (6)
	0.28 (5%)
	0.36 (80%)
	0.64 (9%)
	0.72 (3%)
β–radiation	Principally 0.61 MeV (6)
Maximum permissible concentration in drinking water for occupational exposure	0.27 μc/gallon (7)

Iodine 131 is available as a water soluble iodide and preliminary tests carried out in the laboratory showed that the addition of one kilogram of potassium iodide carrier to each 50 mc of iodine 131 would prevent any significant adsorption of the tracer on the mud of the pond. It was calculated that 500 mc of iodine 131 would be the optimum quantity for one test and this was available at a satisfactory price in Sydney by air delivery from the U.K.A.E.A. Radiochemical Centre at Amersham, England.

The γ–radiation from iodine 131 is almost ideal for this type of work. It is sufficiently soft to give high counting efficiency in a small scintillation crystal and, because of the water shielding effect, only the iodine 131 within a volume of 8 in. radius is detected. This enables accurate measurement of concentration gradients. The soft radiation also means relatively low air transport cost as very little shielding is required.

To avoid unnecessary loss of the radioactive isotope by decay, the whole experiment was carefully synchronised with delivery from the United Kingdom. The shipment arrived in Sydney on the afternoon of March 12th, 1958, at a nominal activity of 500 mc. It was introduced into the pond at 7.30 a.m. on 13th March at an actual activity of 473 mc.

3. DETAILS OF RADIATION DETECTION EQUIPMENT

Gamma rays from the iodine 131 in the pond were detected by two types of counter; Geiger and scintillation. The scintillation counters, because of their high gamma sensitivity, were used to measure low concentrations of iodine 131 in water, and the less sensitive Geiger counters for high concentrations, i.e. in the first hours of the experiment. It was not possible to determine iodine 131 concentrations above 1 μc/gallon with the scintillation counter, due to the limitations of the associated electronic apparatus at high counting rates.

The scintillation counter consisted of a NaI (Tl) crystal, of diameter 1½ in. and height 1 in. mounted in a head designed by Jefferson (8).

This is a light-tight, hollow aluminium cylinder containing the photo-multiplier and dynode resistors. The head was connected to the associated electronic apparatus by means of a long, low capacity coaxial cable (up to 60 ft. long and of capacity approximately 11 pF/ft.). Three scintillation counters were used; one, permanently installed at the pumphouse, continuously recording the iodine 131 entering the intake pipe, and the other two in boats, for measuring the activity at various parts of the lake. At the pumphouse, the cable from the scintillation head was connected to a Burndept Ltd. type 1186 A amplifier, in series with an EKCO ratemeter type 1037B (modified for scintillation counting) and a Leeds and Northrop "Speedimax" chart recorder. In the boats, the cable connection was to an Airmec type 1021B radiation monitor. The 240 V. A.C. supplies for the monitors were obtained, in one boat, by a battery-operated motor generator, in the other from a cable connected to A.C. mains ashore.

Each of the two Geiger units used consisted of a water-tight aluminium cylinder, containing three halogen quenched type CV.2147 counters, connected by a 6 ft. cable to a transistorised portable field ratemeter, Ericsson Telephone Ltd. type 1368A.

The type of water-tight cylinders in which the scintillation head and Geiger tubes were enclosed is shown in Fig. (2). The walls of the cylinder were thin (1/16 in.), and were made of aluminium, so as to reduce γ-ray absorption. The cylinders were weighted so as to be slightly more dense than water, and were suspended at the required depth of water by a wire connected to a cage in which the cylinder was placed. The depth of immersion was marked off on the coaxial cable. Fig. 3 shows the complete assembly of the scintillation detector.

4. CALIBRATION OF RADIATION DETECTION EQUIPMENT

All the detection instruments used in the test were calibrated in terms of radio-activity of iodine 131 per gallon of water.

The calibrations were carried out by immersing the detection unit of the instruments in a 44 gallon drum containing 40 gallons of water and a known activity of iodine 131 with inactive potassium iodide carrier. It was necessary to ensure that the volume of the water contained in the drum represented an "infinite volume" to the detection instrument. The calculated half-thickness of water for iodine 131 radiation is about 2½ ins., the diameter of the drum was 23 in. and its height 3 ft., hence the detector, if placed in the middle of the drum, should detect very nearly 100% of the activity of an infinite volume. This was confirmed experimentally by lowering the detector into the iodide solution along the centre-line of the drum and taking readings with depth. For both the scintillation heads and the Geiger counters, the maximum reading was reached with the detector at a depth of about 8 in. and this reading stayed constant with the increasing depth until the detector was within about 8 in. of the bottom of the drum when the reading decreased with increasing depth. This indicated that the effective infinite volume was a sphere of 8 in. radius; hence with the detector placed along the centre line of the drum and about 12 in. from the bottom, it was effectively in the centre of an infinite volume.

During the calibration, the detection units of the instruments were placed, one at a time, in the centre of the drum of iodine 131 solution and the reading noted. The background reading was subtracted from this and the nett reading plotted against the iodine activity. The procedure was repeated for increasing activities of iodine in the drum. Figures (4) and (5) show the calibration curves obtained for each instrument. The discrepancy between the readings of the 1021B and the 1037B ratemeters at high iodine concentrations is due to their different paralysis times.

The observed variation of counting rate between the surface and a depth of 8 in. was used to determine correction factors (Table 1) for measurements taken near the surface of the pond.

TABLE 1

CORRECTION FACTORS FOR READINGS NEAR SURFACE

Depth (Inches)	Correction Factor	
	1021B (Scintillometer)	1368A (Geiger Counter)
Surface	1.56	1.5
1	1.35	1.4
2	1.23	1.4
3	1.15	1.3
4	1.10	1.3
5	1.07	1.2
6	1.04	1.2
7	1.02	1.1
8	1.00	1.1
12	1.00	1.0

5. BACKGROUND MEASUREMENTS AT THE COOLING POND

Before the actual test a series of background measurements at various depths was undertaken to get accurate information on this factor with each type of instrument. A number of readings was taken at various points in the pond and the results were very consistent. Table 2 gives the average figures obtained.

TABLE 2

BACKGROUND MEASUREMENTS AT VARIOUS DEPTHS

Depth (Position of NaI crystal). (feet).	Background Activity	
	1021Bwith scintillometer (c.p.s.)	1368A with Geiger counter (mr/hr).
In air over land	50 - 70	-
In air above pond	25.0	0.008
Surface	7.0	0.005
1	2.5	0.005
2	2.0	0.005
3	1.7	0.004
4	1.5	0.003
5	1.4	0.003
6	1.4	-
7	1.3	-
8	1.3	-
9	1.2	-
10	1.1	-
11	1.1	-
12	1.0	-
Below 12	1.0	-
Bed of pond	16.0	0.005

These results indicate that the main component of the background of the scintillation unit is a soft γ-ray which is absorbed by a very small amount of water. There is indication also of a very hard component as evidenced by the slow reduction in residual background down to 8 - 9 ft. The excellent shielding provided by the water and its freedom from activity gave ideal conditions for very sensitive detection of the iodine 131. Because of the low background, quantities of iodine 131 down to 0.001 μc/gallon were detectable. The backgrounds for the 1021B and 1037B ratemeters were identical.

The sum of the activity on the pond bed and the air activity over the pond added up almost to that obtained over land as would be expected. The difference could possibly be explained by higher airborne activity over the land, and water shielding reducing the bed activity relative to the dry soil contribution.

No similar advantage from shielding by the water was experienced with the Geiger counters. However, these were used only for high activity levels in the early stages of the experiment.

6. DESCRIPTION OF EXPERIMENT

(a) Method of addition of tracer

With the quantity of iodine 131 used (473 mc), certain precautions against external radiation dangers were necessary just prior to addition of the solution to the pond. This quantity of iodine, unshielded, gives a γ-radiation level of about 130 mr/hr at 3 feet. All handling was carried out rapidly with 6 ft. tongs so that significant exposure to any person was unlikely. This was confirmed by film badges worn by all operators.

The apparatus for adding the iodine 131 in potassium iodide carrier is shown in Fig. (6). It consisted of a 5 gallon drum made up in the form of a "flying fox" operating on a cable which passed across the end of the discharge channel. The drum was free to rotate at the point of attachment of the stirrup so that the contents could be ejected by pulling the rope attached to the base. This rope passed over a pin just below the pulley and is shown clearly in Fig. (6).

A solution of 20 lb. of potassium iodide in about 4 gallons of water was made up in the drum in the position shown in Fig. (6). The iodine 131 was supplied, carrier free, in three small bottles which were separately introduced into the drum via a 1 in. I.D. steel tube to which was attached a flat steel base 6 in. in diameter. This operation is shown in Fig. (6). The bottle was then broken under the solution by forcing the steel plunger (shown beside the tube) into the tube and crushing the bottle against the steel base. A hole in the tube at the base allowed the iodine 131 to escape into the solution. The tracer was mixed with the solution by using the breaking device as a stirrer. When mixing was complete, the drum was raised from its base and sent down the cable until just above the proposed point of injection. This point is shown in Fig. (10). The tracer solution was then tipped into the channel by inversion of the drum as shown in Fig. (7). The bottle breaking equipment was left in the drum and tipped out into the water with the solution. It was recovered later by an attached rope. This procedure avoided contamination of the mixing area which would have resulted from prior removal of the stirrer.

Twenty pounds of fluorescein dye was added at the same time and location as the radio-isotope in order to check the agreement between dye and isotope used as tracers and to provide a visual indication of the location of the isotope for purposes of quantitative measurement. In general, the surface movement of the tracer followed the fluorescein but the latter ceased to operate as an effective tracer after about 4 - 5 hours. The fluorescein was of no value as an indicator of vertical mixing.

The radioactive tracer was added rapidly so that a relatively small volume of condenser water would be "labelled". It was felt that this would give a clearer picture of the subsequent distribution than would be obtained by adding the tracer slowly.

(b) Detection of radioactivity distribution and movement

The distribution of the radioactively labelled water was followed in three dimensions in the lake using the scintillation and Geiger counters described in previous sections. Figs. (8) and (9) show the scintillation and Geiger units in use. The counters were carried in small boats and, in general, the less sensitive Geiger counters were used only in the earlier stages, when the concentration was relatively high.

Location of position was made by reference to cables strung across the pond as grid lines and the depth was marked on the co-axial cables of the detecting units. Measurements of activity were made at the surface and at depths in the pond at intervals of 1 or 2 feet until background readings were reached. About 3,000 readings were made over a period of 8 days and the activity recorded against position, time and depth. Conversion of activity in counts per second from the calibration shown in Figs. (4) and (5) into concentration of iodine 131 involved prior correction for the variable background, decay and geometrical factors near the surface. All observations were corrected back to activity at "zero" time, viz. 7.30 a.m. on 13.3.58.

(c) Weather observations.

During the whole test, observations of temperature, humidity and wind velocity were made at regular intervals. The wind velocity is particularly important as previous experiments with fluorescein showed that it could have a marked effect on the movement of the water in the pond. In a tracer test this is particularly important during the early stages where most of the labelled water is still warm and is concentrated on the surface. Fortunately, weather conditions were very mild during the whole experiment, with low wind velocities and steady temperatures. However, the observations, particularly on the first day, did show the effect of even a small increase in wind velocity.

7. PRESENTATION OF RESULTS.

(a) Movement of surface water.

The warm labelled water, after discharge into the pond, spread out rapidly over the whole surface. In the early stages, therefore, the surface observations are of greater significance and these are recorded in Figs. (10 – 19). Readings for the first day are recorded for shorter more frequent intervals than for subsequent days. In plotting these charts, the radius of the circle is proportional to the activity found at its centre. The first three charts, where the activity is higher, are plotted on a scale which is one tenth of the scale for the subsequent charts. On each chart, the relevant wind velocities and times of observation are recorded.

(b) Intake recorder.

In Fig. (20) the concentration of iodine 131 at the pump house intake is plotted against time. The relevant weather information is also indicated. Since volume flow of water is proportional to time, the integral of this curve in the appropriate units gives the total quantity of iodine 131 which is proportional to the total amount of the original "labelled" water which has passed through the power station at any given time. The integral curve is plotted in Fig. (21). Under the circumstances of this experiment, this integral curve loses significance after the first inflexion as the iodine is then being recycled.

(c) Variation with depth.

In Figs. (22) to (31) the variation of iodine 131 concentration with depth is shown at various times. In the early stages, these concentrations varied somewhat over the pond and the average curves for the north, south and east arms of the pond have been plotted, except where significant variations occurred within each arm, Fig. (23).

It was noticed at all times that the lowest depth of penetration of the radioactive layer was quite sharply defined. This depth is plotted against time in Fig. (32).

8. DISCUSSION OF RESULTS

(a) Surface flow

In the first few hours most of the flow of the warm labelled water will be on the surface because of its lower density, until substantial cooling occurs. The activity/depth graphs in the early stages confirm this fact which had already been shown qualitatively with fluorescein. For the first 4 – 5 hours, the pattern of surface activity very closely followed the fluorescein, which subsequently became invisible by dilution. The high surface activity observed in the first 90 minutes, Fig. (10) rapidly dispersed by spreading as shown in Figs. (11) and (12) and surface indications first appeared near the pump house between 10 and noon, before any had penetrated into the south arm. From noon to 2 p.m., Fig. (13) a moderate dispersion back into the south arm was evident, although the main activity appeared to be concentrated near the pump house. Until this time, the wind speed and direction had not been significant factors in affecting the movement of the surface water. However, between 3 and 5 p.m., the wind increased and changed direction. The effect of this is quite clear in Fig. (14), in that the surface layer has been forced back into the north arm against its normal flow. It is not possible to say whether the wind had any effect on the concentrations in the south arm as these measurements were made before the change in wind. The north arm also shows the return of the active water which had passed through the station and is appearing at the discharge channel.

By the evening of the first day, the wind had dropped and the observations were marked by uniformity of distribution of surface activity Fig. (15) with a tendency for slightly higher levels in the east and south arms.

The magnitude of the surface activity during the first day showed an initial rapid decrease due to spreading and subsequently a more steady decrease due to the relatively slower vertical mixing. The continuation of this steady decrease during subsequent days is shown in Figs. (16) to (19). After the first day, the influence of the wind was less marked because the active layer was so much deeper but, with the stronger winds of the afternoon of the second day Fig. (18), there is evidence of "backing up" in the north and south arms. At this stage, the labelled water had penetrated to at least 10 ft., Fig. (27), with the same activity at 10 ft. as on the surface. The evidence appears to indicate a possibility that moderate winds can cause turnover of water to such depths. This is confirmed by the activity/depth curves described later.

(b) Monitoring of water entering power station via Pump House

Fig. (20) shows the rate at which the labelled water, which was discharged from the channel at 7.30 a.m. on 13.3.58, reached the power station. Any early appearance of radio–activity indicates rapid re–circulation of part of the warm water. With complete mixing of condenser water in the pond, the average residence time would be about 9½ days.

The large peak of activity which appeared in the power station water after an interval of only 3½ hours shows a serious channelling effect. It seems that the warm water was moving rapidly over the surface, in the absence of wind resistance, and appearing at the intake which is only 5 ft. below pond surface. This surface movement is clearly seen also on the charts, Figs (12) and (13) and the rise in activity at the pump house occurred at the same time as the surface activity reached the extreme end of the east arm.

The pulse of activity in Fig. (20) reached a maximum at about 5 hours and then rapidly dropped. The rapid drop is accentuated by the wind action which also caused the subsequent trough. This is shown clearly in Fig. (14). The subsequent rise between 12 and 14 hours is due to redistribution after the fall in wind velocity.

With a hold up time of about ½ hour in the power station and a delay period of approximately 5 hours from channel outlet to intake peak, it would be expected that the reheated water from the first pulse would reappear after a total time of about 10½ hours in a somewhat smaller pulse. There is no evidence of such a pulse in Fig. (14). However, from consideration of the dilution experienced between the injection point and the pump house, where the volume passing through in the first pulse between 3½ to 8 hours was 4 m gallons, it is unlikely that the second peak would have been very significant without the wind effect. Rough calculations show that any second peak would be less than one tenth the height of the first and considerably extended. Without the wind effect, the fall of the first peak would have been much slower and a small second recycling peak or fluctuation might have been seen.

Subsequently, the activity passing through the station fell slowly as mixing occurred. The mixing was complete after about 8 – 10 days and after this the corrected iodine 131 concentration was substantially constant for a further 20 days when the measurement at the pump house was stopped.

Fig. (21), in which the integral of the curve in Fig. (20) is plotted against time, shows that at the end of the first peak (8 hours), 80 millicuries of iodine 131 had passed through the power station. With the total activity of 473 mc this means that a fraction 80/473 or 17% of all the outlet water was re-entering the power station within 8 hours. This is only a small fraction of the residence time if complete mixing is obtained. This percentage would be higher but for the effect of the wind on the afternoon of the first day and could have been higher still, if the prevailing winds were driving the surface water towards the pump house. This factor indicates that the performance of the cooling pond could be improved if rapid re-circulation could be prevented.

The significance of the curve in Fig (21) is doubtful after 10 – 12 hours as it was impossible to determine how much of the iodine 131 passing through was on its second or third time round. Up to 10 – 12 hours, it is certain that it had only been through once.

(c) Vertical Movement

One of the greatest values of the isotope tracer method over other techniques is the ability to measure vertical movement quantitatively.

While the water was still warm during the first 2 – 3 hours there was practically no indication of any depth penetration beyond 1 – 2 ft Significant depth measurements were first plotted after 10 a.m., Fig. (22). By this time, there was practically no activity below four feet, with the major concentration in the east arm This corresponded with the migration of the active surface water towards the intake about this time At this stage, the north arm had been diluted by in-flow of inactive water and little activity had penetrated to the south arm.

The first evidence of substantial vertical penetration was shown later that day when the mixing was probably assisted by the wind, Fig (23) The surface activity was lower, but there was an increase in activity at 3 – 4 feet except in parts of the south and east arms where the wind had caused a reduction. The build-up of concentration in the north arm and the north sides of the other arms by the wind action is seen clearly in Fig. (23). These results indicate that substantial movement to a depth of 3 or 4 feet can be caused by even moderate winds.

By the evening of the first day, the wind had dropped and a uniform redistribution of the activity occurred very rapidly as shown in Fig. (24). Penetration to 8 or 10 feet was now evident everywhere.

An interesting effect occurred overnight in that there appeared to be a build-up of concentration at depth at the expense of the surface as shown in Figs. (25) and (26). This could be explained by surface cooling causing a temperature inversion during the night. The night was clear and still with conditions ideal for surface cooling. This hypothesis is substantiated by the fact that the effect was most marked in the south arm, which the earlier charts show to be out of the path of the main stream of warm water. The inversion was not apparent in the north arm, the surface of which was continually receiving warm water from the station. The higher total amount of activity in the south arm during the morning compared to the rest of the pond may be due to the inversion removing some of the active water from the general circulation which is predominantly on the surface. Further support for the temperature inversion theory is given by the recovery to "normal" conditions later in the second day, Fig (27). There was strong solar heating most of this day.

Subsequent observations indicated by Figs. (28) to (31) on following days showed that substantially uniform distribution had been achieved by the third day and the only observable effect was a slow increase in the depth at which radioactive water was observed. The penetration to a depth of 20 to 22 feet, observed after 8 days, indicates that at this stage the radioactive water had mixed with 95% of the water in the pond.

In Figs. (29) to (31) the depression of activity near the surface is probably due to an instrumental factor. Near the surface the reading is very sensitive to the position of the crystal because of the rapidly changing geometry factor and background, and it was difficult to locate it exactly at the surface when enclosed in the water-tight jacket.

The rate of downward movement of the radioactive water is shown in Fig. (32) where the lowest depth at which activity was detected is plotted against time. As expected penetration was quite rapid in the early stages, slowing down when the pond bed was approached. The relative positions of the curves are obviously related to the depth of the pond in each arm.

(d) Abnormally high readings on bed of pond

Frequently during the experiment measurements were made of the activity on the pond bed, and a few of these were substantially higher than normal background. A survey of the bed was also made towards the end of the experiment. The results are shown in Fig. (33). The activity on the bed of the shallow channel can easily be explained by adsorption from the relatively concentrated solution passing through after the first active peak. Very high activity on the channel bed occurred near the injection point and this is readily explained by adsorption from the high concentration at injection. Activity near the edge of the pond was established to be due to adsorption on the pond weed but it is difficult to account for the consistently occurring activity on the bed in the centre of the south arm. It may be naturally occurring activity and could be investigated before the next experiment No preliminary background readings were made here. However, none of these adsorbed activities is sufficiently high to affect the results of the experiment or constitute a health hazard but they do indicate slight adsorption possibilities even with inactive iodide carrier present. The opportunities for adsorption were small because most of the observations in the pond were made before the iodine 131 came into contact with the mud or weed on the bed.

(e) Anomaly in amount of Isotope found in Pond

An anomaly, for which no satisfactory explanation can be found, occurred in the results. The amount of iodine 131 added to the pond, as calibrated at the Radiochemical Centre, Amersham was 473 mc. The depth of penetration of the isotope layer and the average activity of sections of this layer at any time were known fairly accurately.

By taking the activity of each section and the corresponding section volume, (obtained from a contour map of the pond), the amount of iodine present in that particular section could be determined. Adding the values for each section gave the total amount of iodine present in the pond. The results for different times during the test are shown in Table 3.

TABLE 3

TOTAL ACTIVITY OF IODINE 131 IN POND

Date	Time	Total Activity (mc)
Thursday, 13.3.58	2109 – 2259	785
Friday 14th	0630 – 0800	788
Friday 14th	1530 – 1745	827
Saturday 15th	1040 – 1415	651
Sunday 16th	1030 – 1625	753
Friday 21st	1030	739
	Average	757

These results are reasonably consistent among themselves and about 50% higher than the added amount of iodine, viz. 473 mc. The discrepancy is not unreasonable in a field experiment of this magnitude and there are several possible contributing factors.

A sufficient number of readings over a large area of the pond could not be taken in a short time. Hence, the readings on which these calculations were based were spread over a few hours, during which time there could have been some change in iodine concentration at various positions in the lake.

Readings obtained at the surface of the lake were very sensitive to crystal position and a small error in positioning the crystal could lead to an appreciable error in the iodine concentration recorded. However, surface results consistently agree with results at depth, thus indicating that any surface error is small.

Another possibility was that the calibration of the instruments was inaccurate due to adsorption of some iodine on to glassware, etc., during the preparations for calibration. Accordingly, another batch of iodine 131 was obtained and carrier iodide added while it was still in the original sample bottle. On repeating the instrument calibration with this material, the results were substantially the same as in the original calibration.

It is considered that the discrepancy in the amount of iodine does not seriously affect the value of the results as they apply to the performance of the cooling pond. Most of the information obtained has been based on the relative activities rather than on absolute values. However, in the one case where an absolute value of the activity is required, i.e., in determing the percentage of discharged hot water recirculating through the power house within a few hours, we consider the figure of 473 mc. to be the more reliable.

It is hoped that the discrepancy will be resolved by the next experiment, which will be carried out later this year.

9. RADIATION HEALTH ASPECTS

The lifetime drinking water tolerance for occupationally exposed persons is 0.27 μc/gallon of iodine 131 (7). Approximately 34 of the 3,150 readings taken exceeded this level of activity and these occurred only during the first half hour. Subsequently, the activity dropped well below this figure. The highest concentration entering the power station was about 1/7th of the drinking water tolerance level. The external radiation from this was negligible, and somewhat less than normal background.

Quantitative results under these conditions were achieved by the use of the most sensitive detection instruments available and careful planning of the experiment. Efficient detection methods also enabled the minimum quantity of tracer to be used, reducing both external radiation hazards during mixing and handling, and the cost of the isotope.

All personnel engaged wore film badges. No badge showed a detectable radiation level above normal background. As an additional precaution, radiation monitors were used during the mixing of the isotope and were carried in each boat. In the latter case, no significant radiation was detected in any boat at any time.

The pond contained a few fish and a considerable population of tortoises. As a matter of interest, a fisherman was engaged in an attempt to catch some of the inhabitants of the pond to see whether they had taken up any iodine 131. Repeated trawls with a net yielded no fish and 3 tortoises. The tortoises showed absolutely no γ-activity and the scarcity of fish was probably due to extensive activities by professional fishermen several weeks earlier.

10. SIGNIFICANCE OF RESULTS TO COOLING POND DESIGN

Previously published information on the performance of cooling ponds (9) indicated that when warm water was discharged into a lake or pond for cooling, the warm water spread out rapidly over the whole surface of the pond in a film a few millimeters thick which resulted in a sensibly uniform distribution of surface temperature and equally effective use of the whole of the surface area.

Observations made by the Electricity Commission of New South Wales at seaboard power stations and at a small industrial cooling pond used by a chemical manufacturing plant in Sydney indicated that this was not a true indication of pond behaviour and raised doubt concerning the accuracy of predictions of cooling rates based on this reference which were being used for preliminary design purposes.

Further, the ponds being considered by the Electricity Commission for future use with large inland power stations would require a surface area of the order of two or three square miles. An examination of the hydraulic conditions which would apply to these cooling ponds indicated that the rate of water circulation was such that Reynold's criterion for turbulent channel flow would be exceeded. Consequently, it was desired to obtain information regarding the interplay of the forces due to density differences and those causing turbulent flow as they affect mixing within the pond.

The Maitland Power Station was therefore modified so that part or all of the warm water from the condensers could be cooled in either the existing cooling towers or the cooling pond formed by the neighbouring disused Walka water supply reservoir. Investigations of cooling performance have been in progress at this site since November, 1957.

The isotope investigation formed part of the series being carried out at Maitland. It was included with the objective of obtaining information on the flow patterns and mixing within the cooling pond. With this information the results obtained relating to temperature rise could be more effectively interpreted in terms of performance of the much larger ponds being planned for the future. Further, the better understanding of pond behaviour might lead to improvements in design.

The isotope investigation demonstrated that the warm water is initially confined to the top few feet and flows to all parts of the pond under calm conditions.

A significant proportion of the water discharged to the pond was found to recirculate directly to the power station intake while still in this shallow surface layer. Consequently, the separation between discharge and intake must be sufficient to ensure adequate cooling of the surface layer.

The isotope observations showed that the wind has greater influence on the movement of the surface layer containing the freshly discharged water than the hydraulic gradient established by the circulating pumps. This emphasises the need to adopt, where possible, an arrangement wherein the prevailing wind blows the surface water away from the power station intake. However, consideration of depth of water for a submerged intake may more than offset this factor.

It is anticipated that a submerged intake structure will result in substantially lower temperatures during the summer season when temperature stratification is considerable. A submerged intake is now being constructed at Maitland and it is proposed to carry out a further isotope test with this arrangement during the coming summer season.

The test described in this paper was carried out in the autumn and it was found that at night the surface water was cooled below the temperature of the body of the pond. Consequently, convection currents carried the surface water downward and after only a few days the isotope was mixed with the whole contents of the pond.

11. CONCLUSIONS

This experiment has established the value of radio-isotope tracer techniques in the investigation of water movement in power station cooling ponds. It was possible to follow the movement of the "labelled" water up to the stage of complete mixing, which occurred after 8 – 10 days. No other known form of tracer, such as fluorescein dye or salt dilution methods, can approach the radio-isotope method either in duration or quantitative accuracy.

It has also been shown that selection of the optimum quantity of a suitable relatively short-lived isotope enables such experiments to be carried out with a completely negligible radiation risk to any person.

The experiment was part of an extensive project in which all aspects of power station cooling ponds are being investigated by the Electricity Commission of New South Wales. It is known that the characteristics of water movement vary with the time of the year and further tests are planned in the near future. The effect of variations in intake structure and modifications of the pond will also be studied.

12. ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance of the staff of the Power Development Branch of the Projects Division of the Electricity Commission of New South Wales during the experiment. Thanks are also due to the Power Station Superintendent (Mr. J. Barrett) and his staff for valuable co-operation and for making available the necessary facilities.

The co-operation of the Director and staff of the Commonwealth X-Ray and Radium Laboratory for assistance in expediting the delivery of the radio-isotope from the United Kingdom, and for assessment of film badge readings is also acknowledged.

The permission of the Chairman of the Electricity Commission of New South Wales to publish sections of this report is gratefully acknowledged.

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(8) Jeffersen, S. – Private communication.

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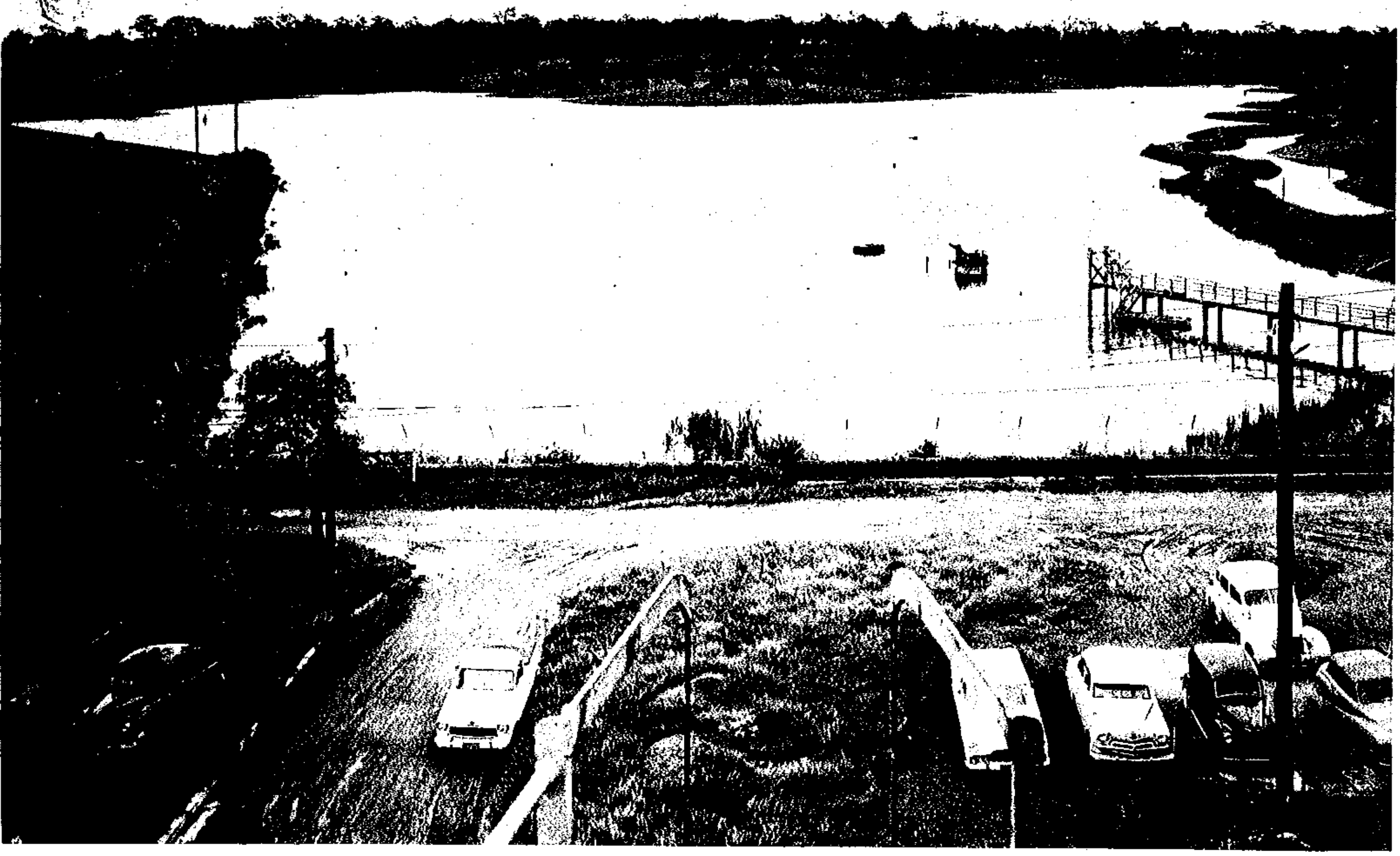


FIG. 1. VIEW OF POND FROM POWER STATION

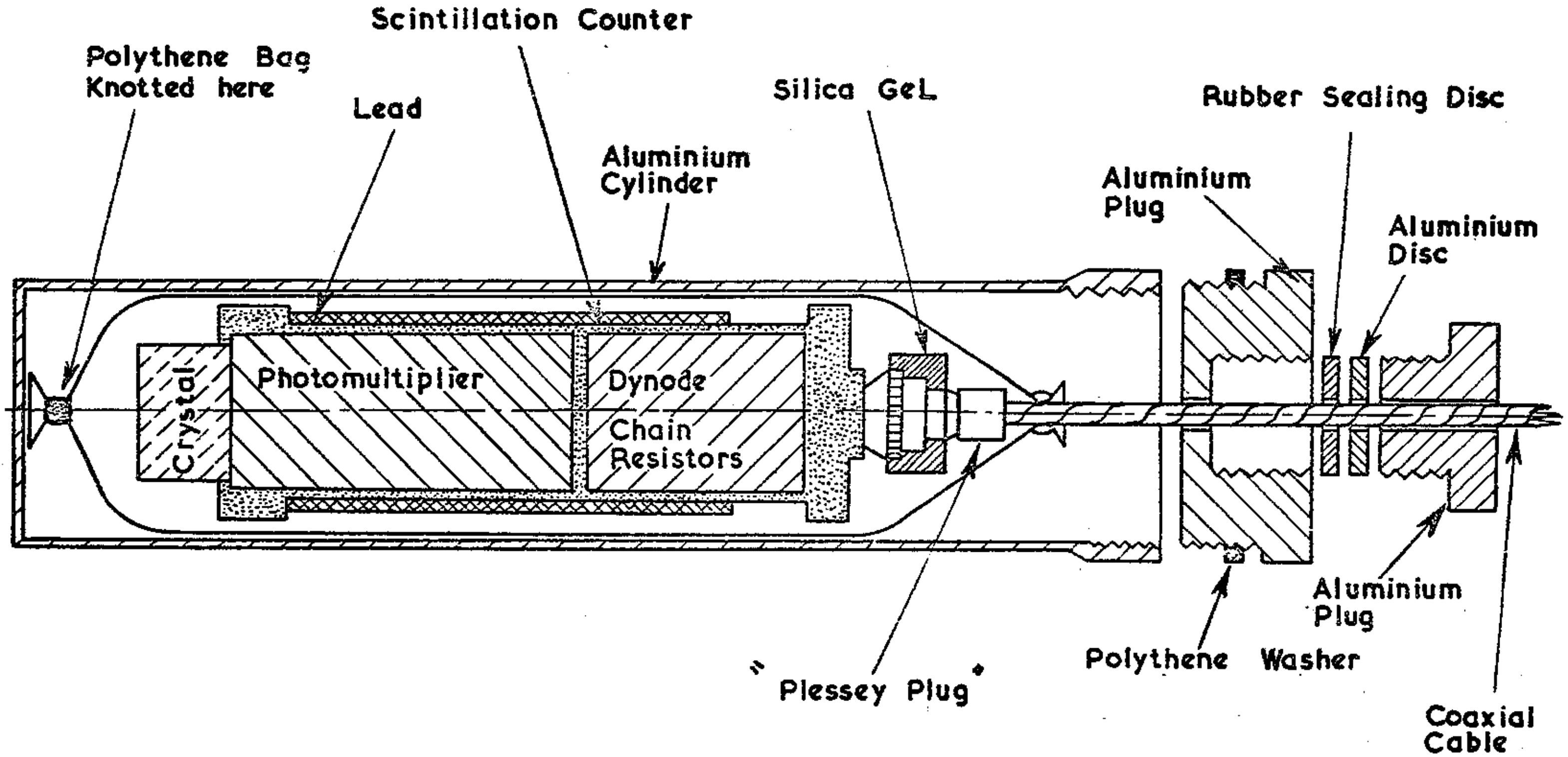

Scintillation Counter
Polythene Bag Knotted here
Lead
Aluminium Cylinder
Silica GeL
Rubber Sealing Disc
Aluminium Plug
Aluminium Disc
Crystal
Photomultiplier
Dynode Chain Resistors
Aluminium Plug
Polythene Washer
" Plessey Plug *
Coaxial Cable

Fig. 2.

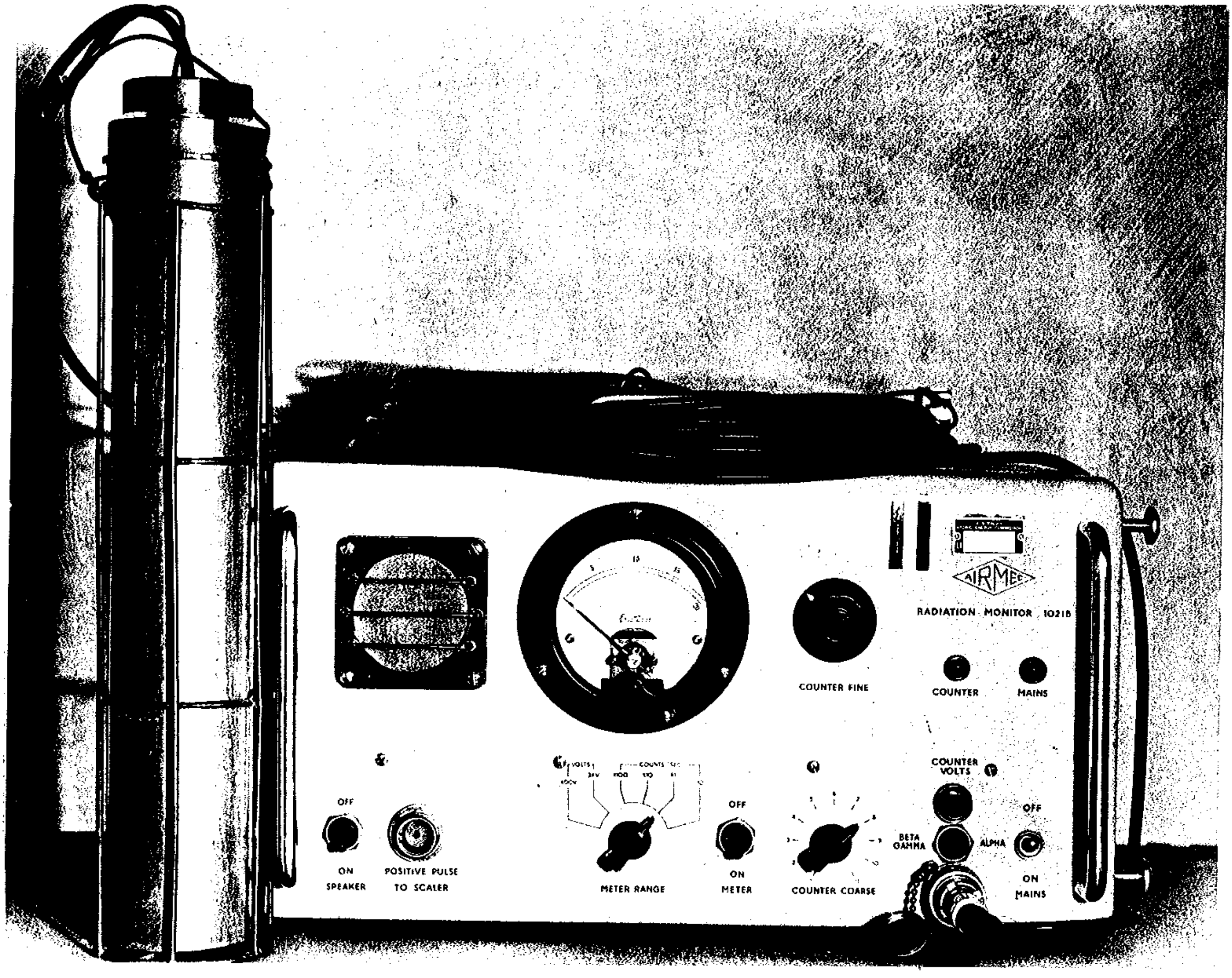


FIG 3. SCINTILLATION COUNTER ASSEMBLY

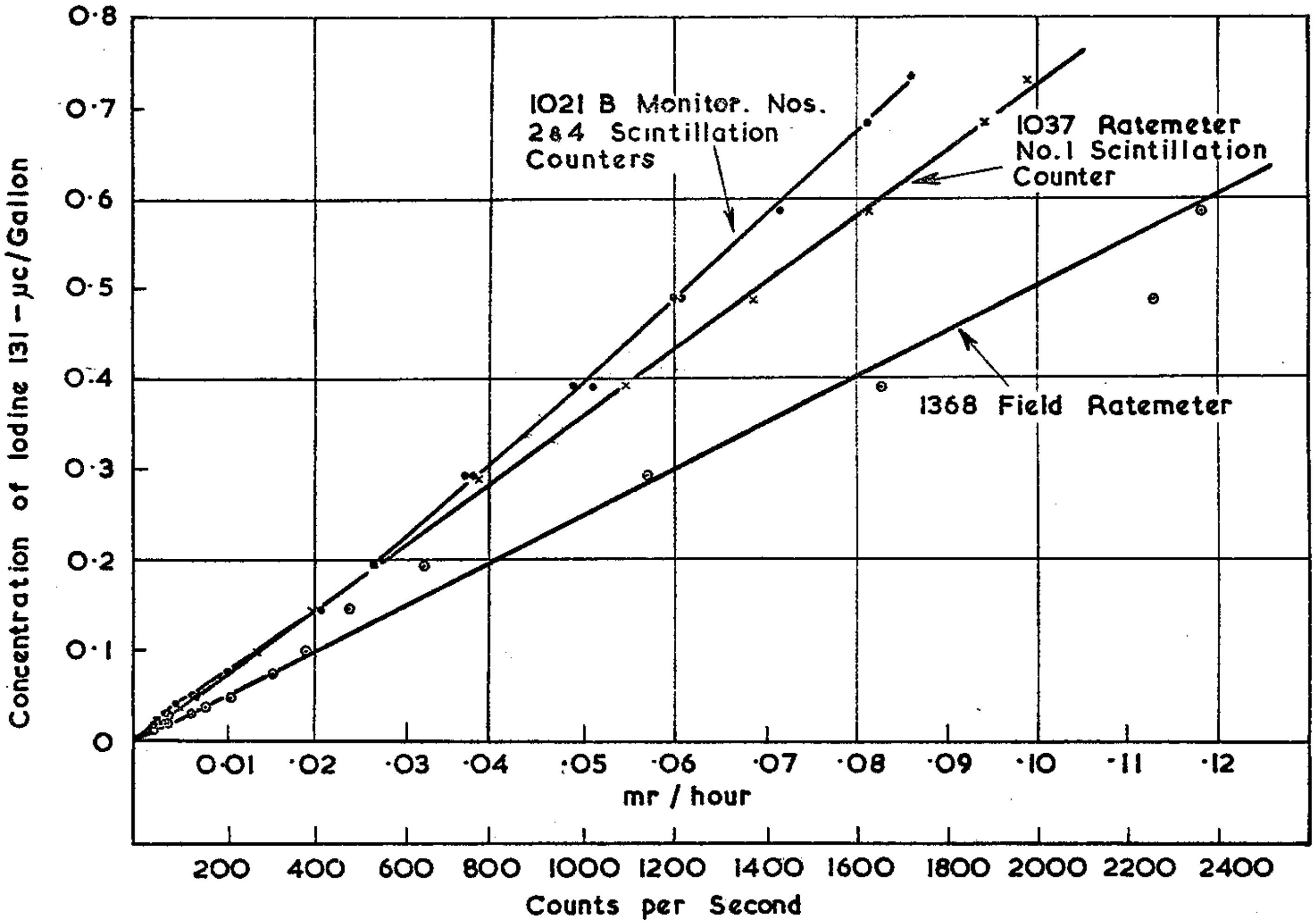


Fig.4. INTERCALIBRATION OF INSTRUMENTS

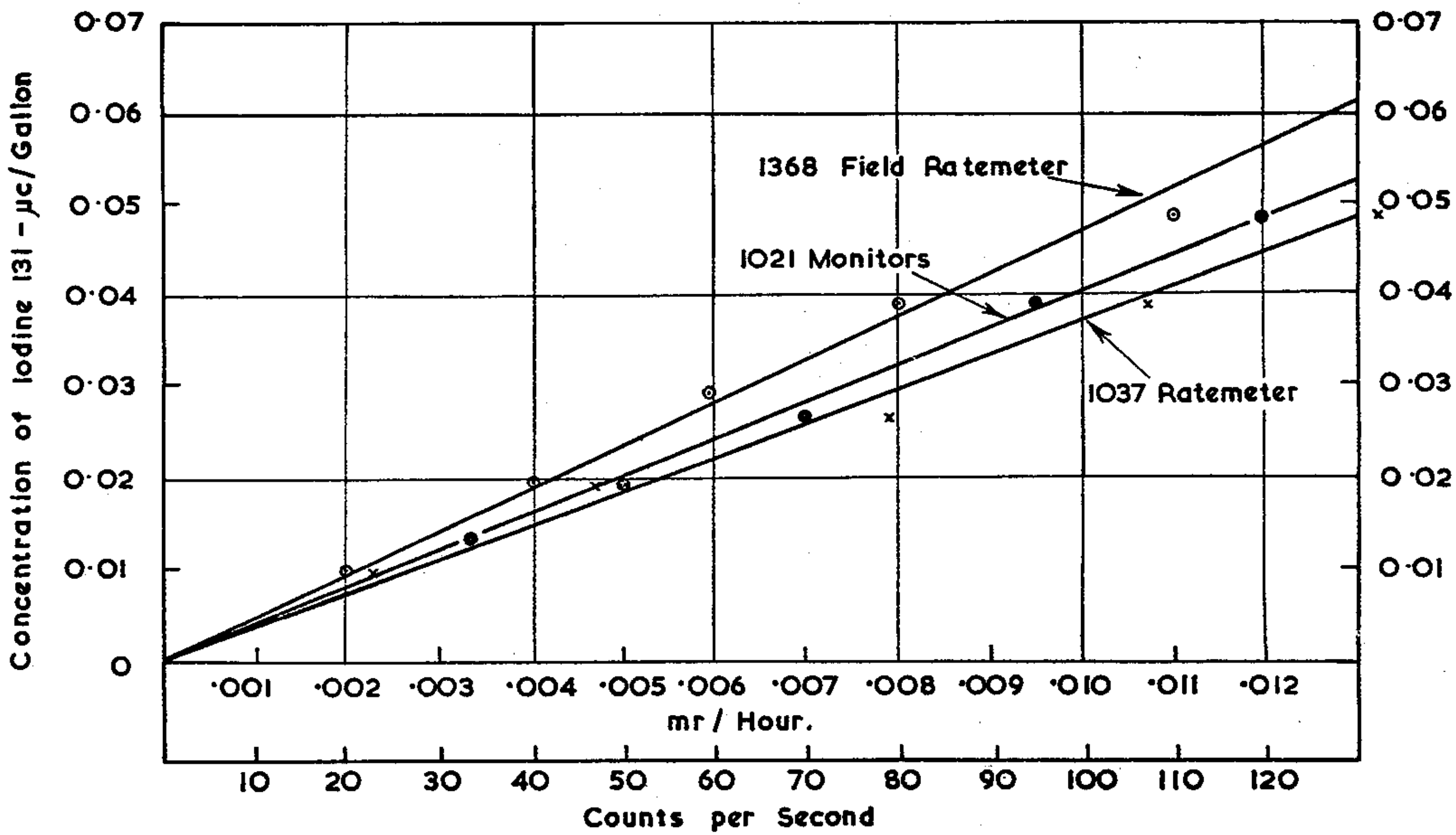


Fig. 5. INTERCALIBRATION OF INSTRUMENTS (LOW END OF SCALE)

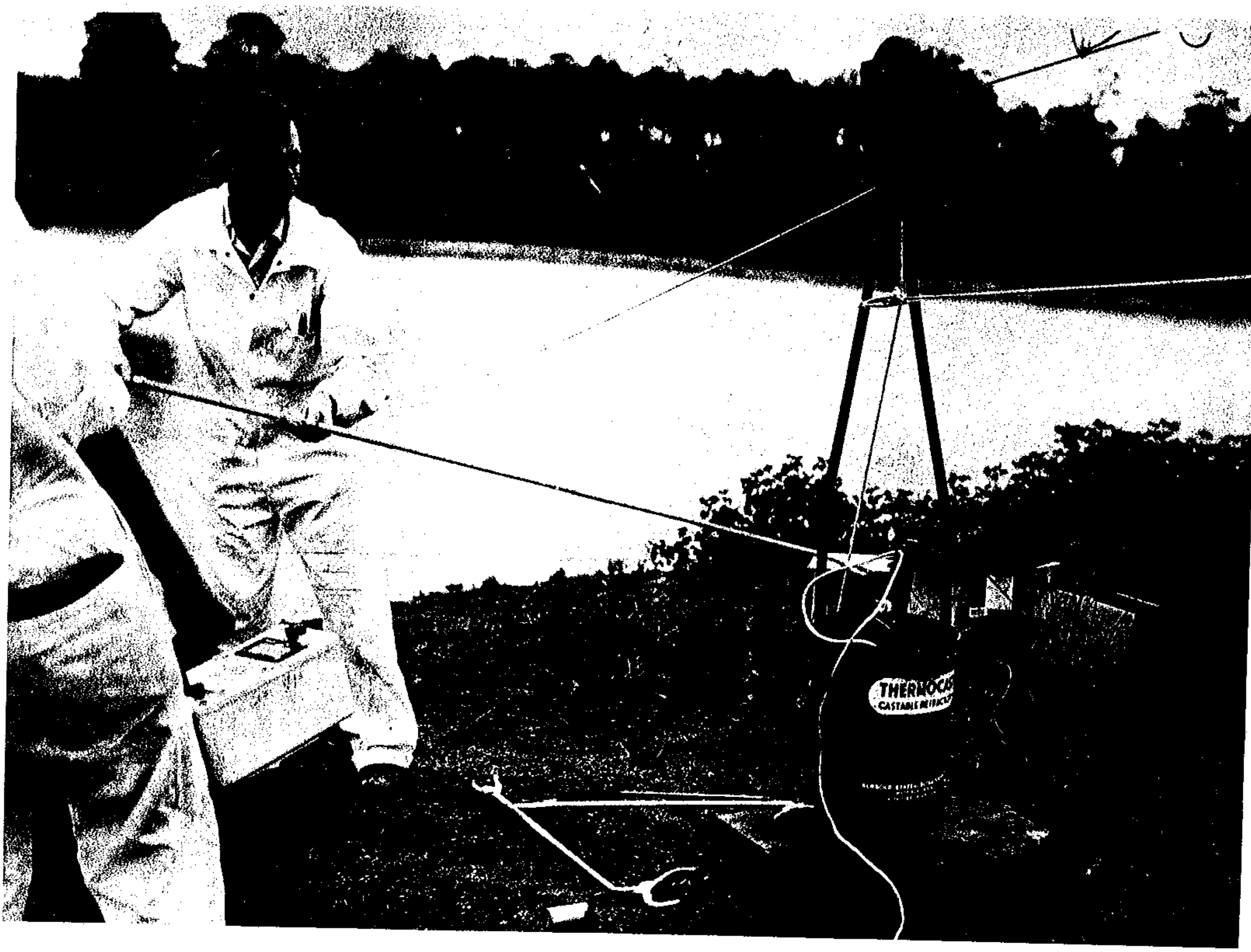


FIG. 6. LOADING ISOTOPE INTO CRUSHING DEVICE

FIG. 7. POURING THE SOLUTION INTO THE POND INLET

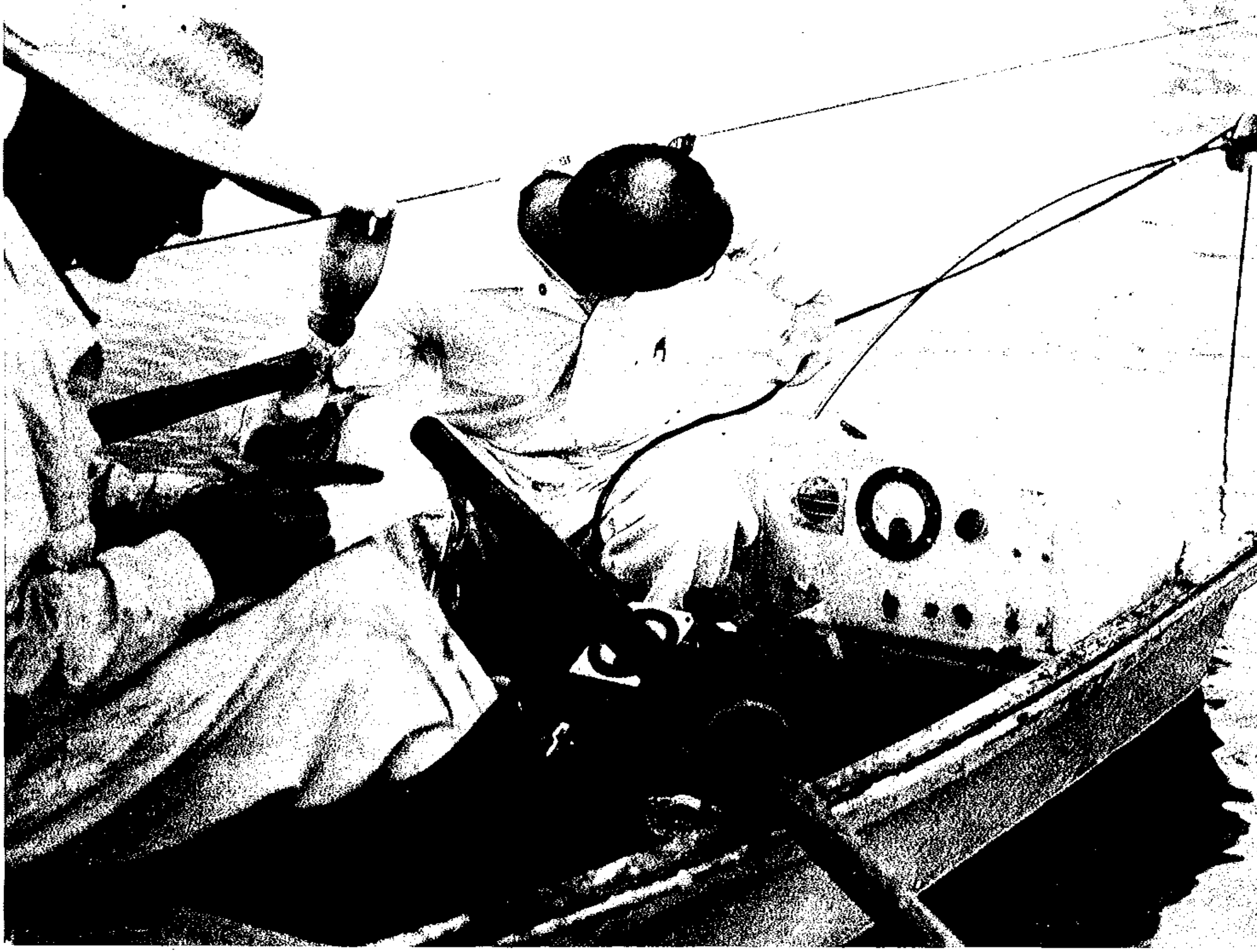


FIG. 8. USING SCINTILLOMETER UNDERWATER RADIATION DETECTOR

FIG. 9. UNDERWATER GEIGER COUNTER

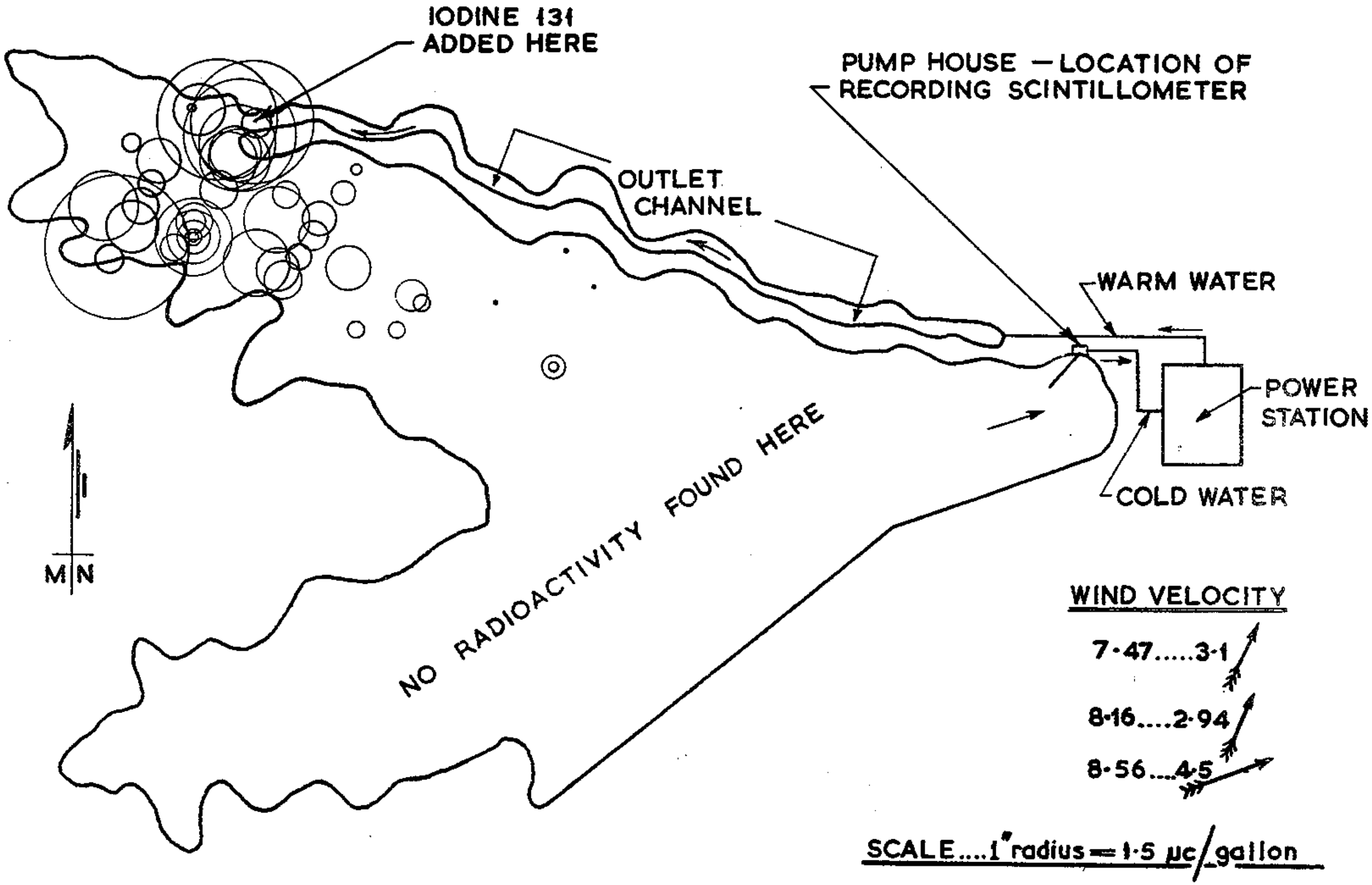


Fig.10 FIRST DAY... 7.30 – 9.00 a.m.

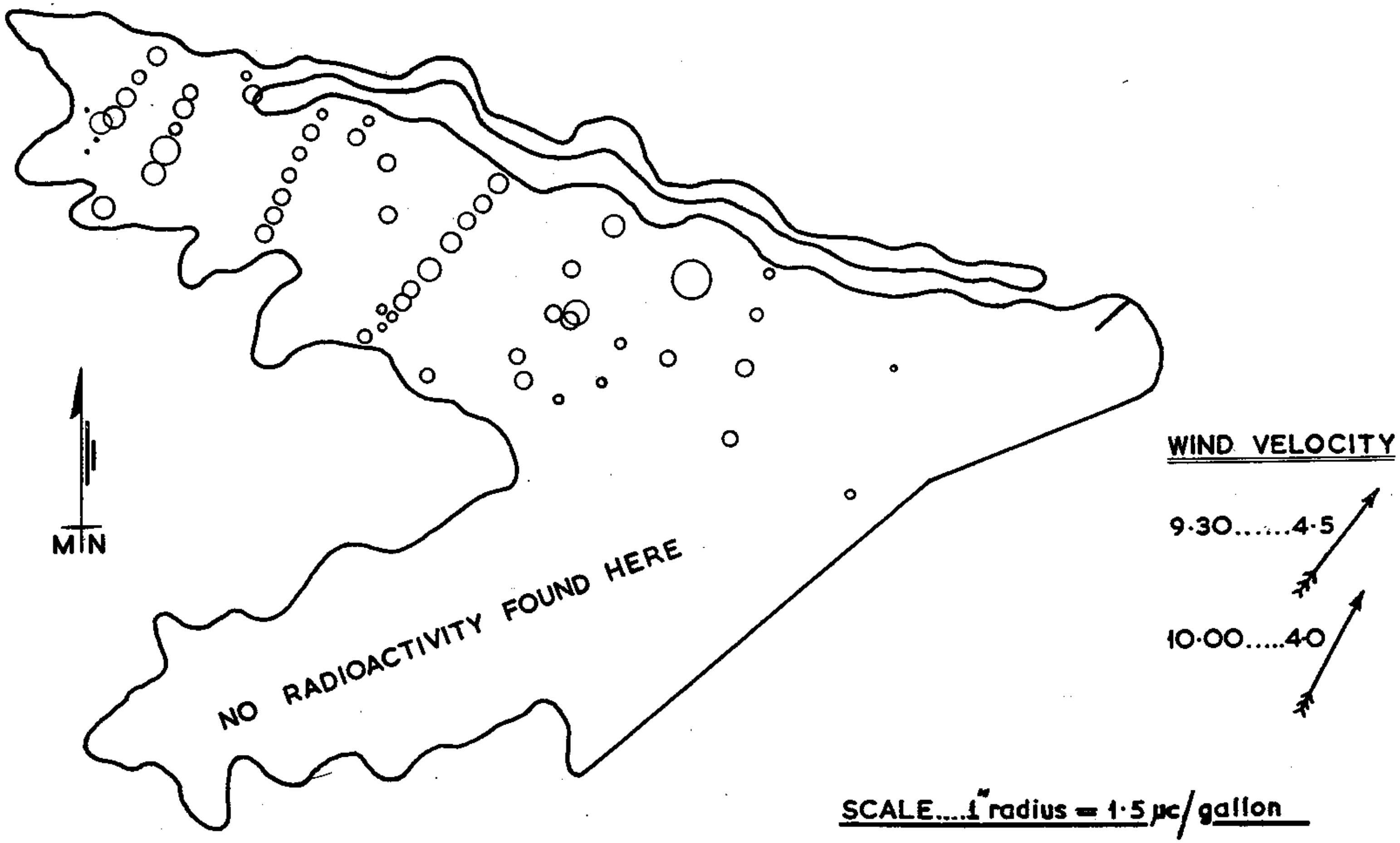


Fig. 11 FIRST DAY ... 9.00 – 10.00 a.m.

P9

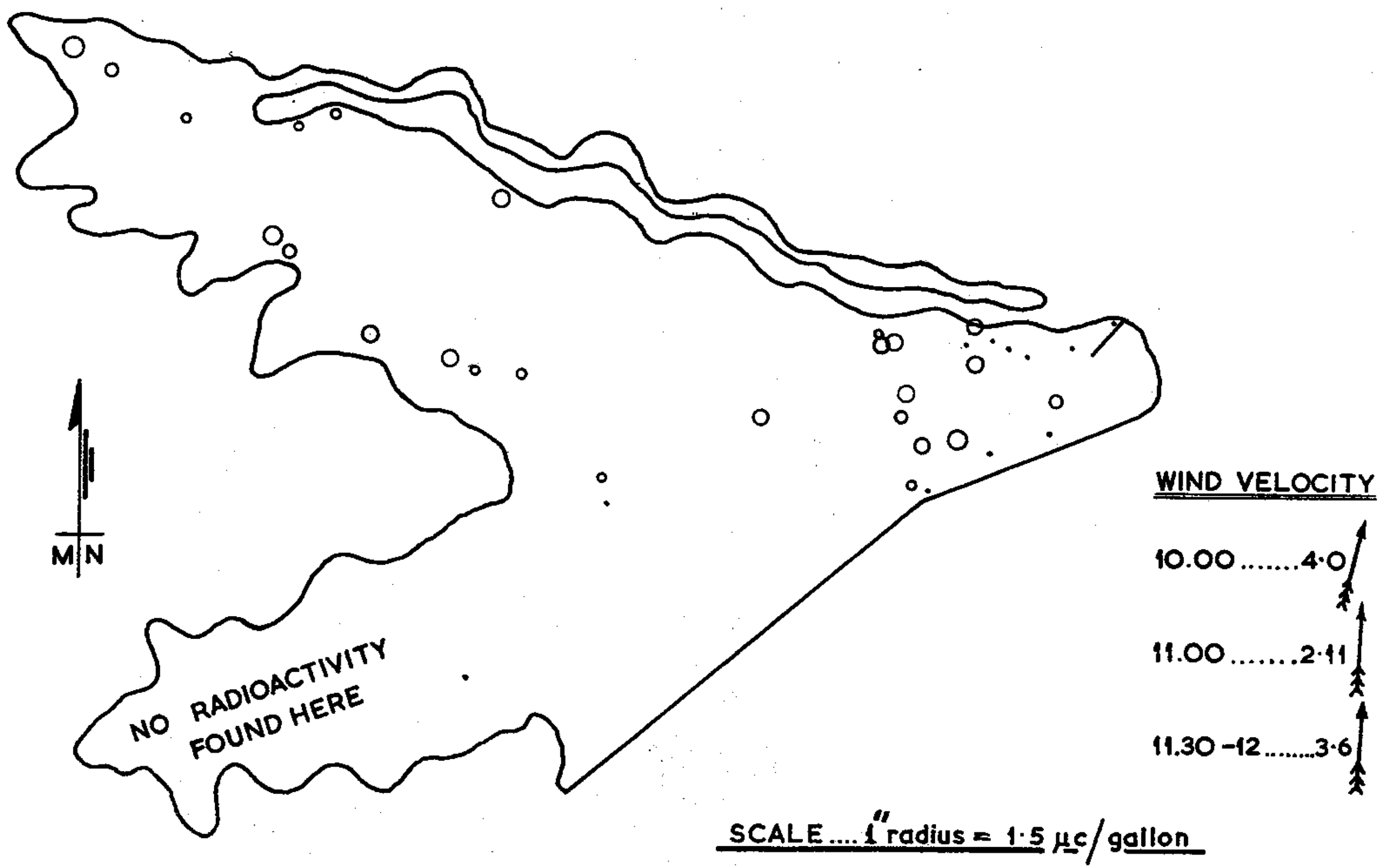
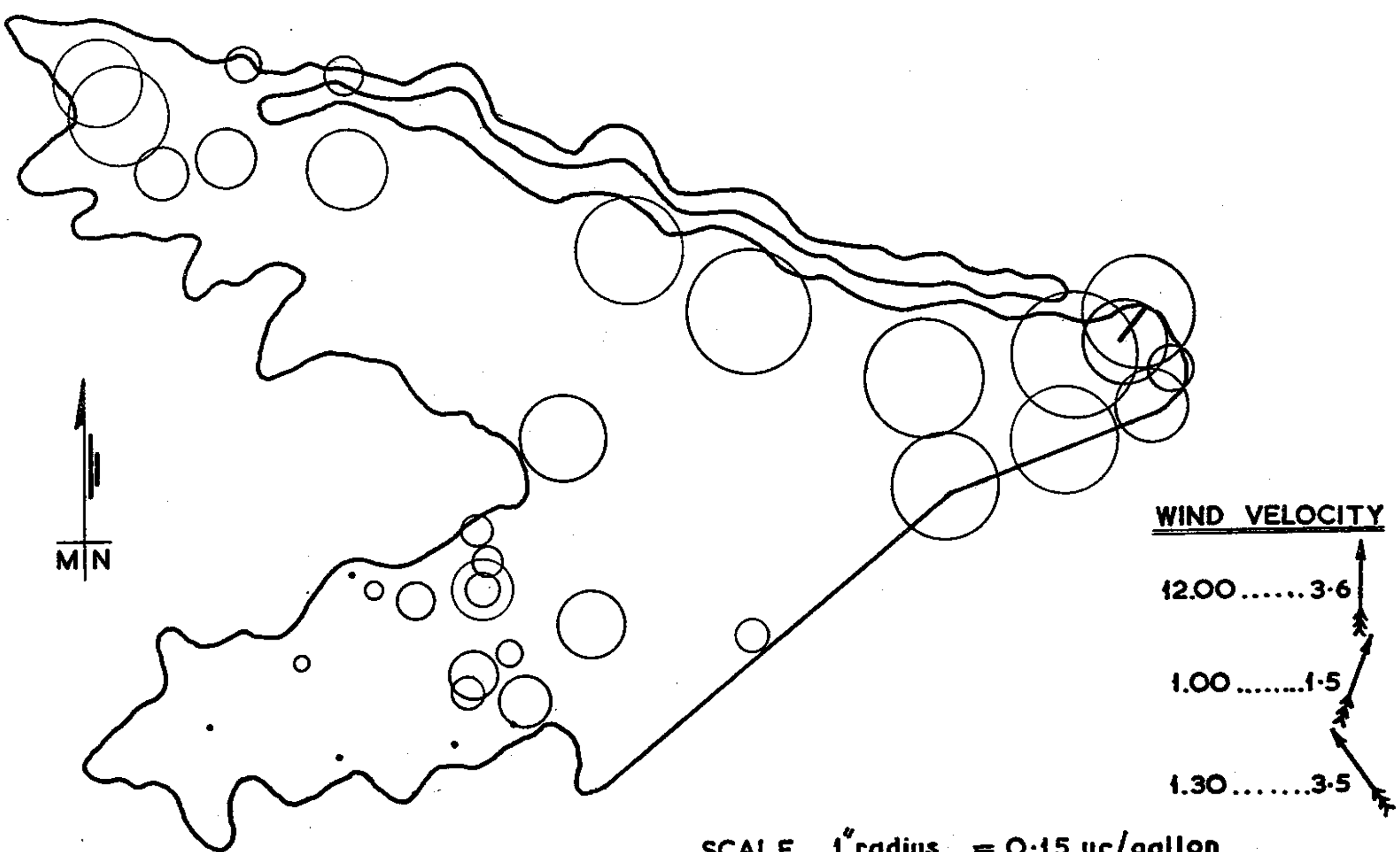


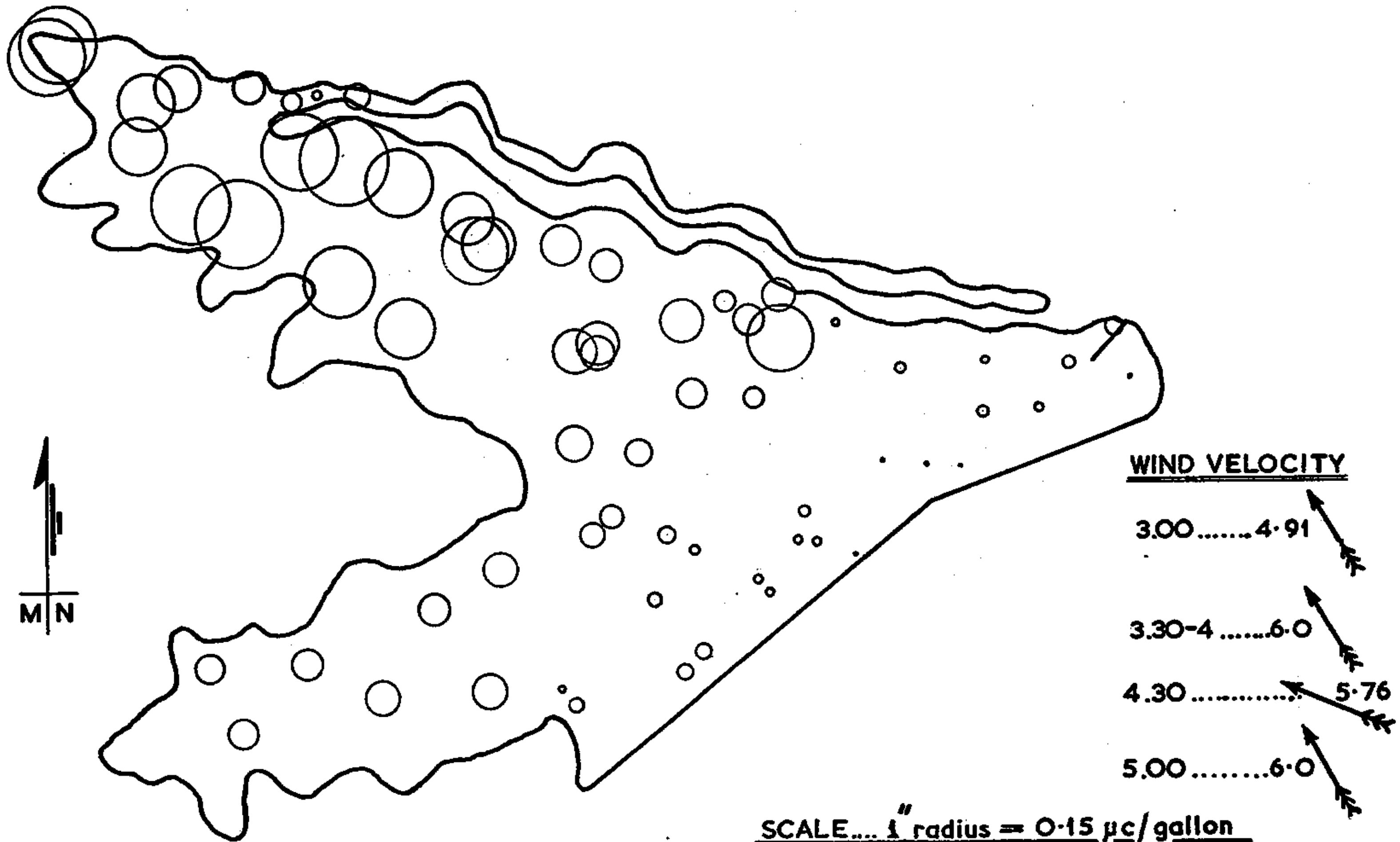
Fig. 12 FIRST DAY... 10.00 a.m. – NOON



SCALE....1" radius = 0·15 μc/gallon

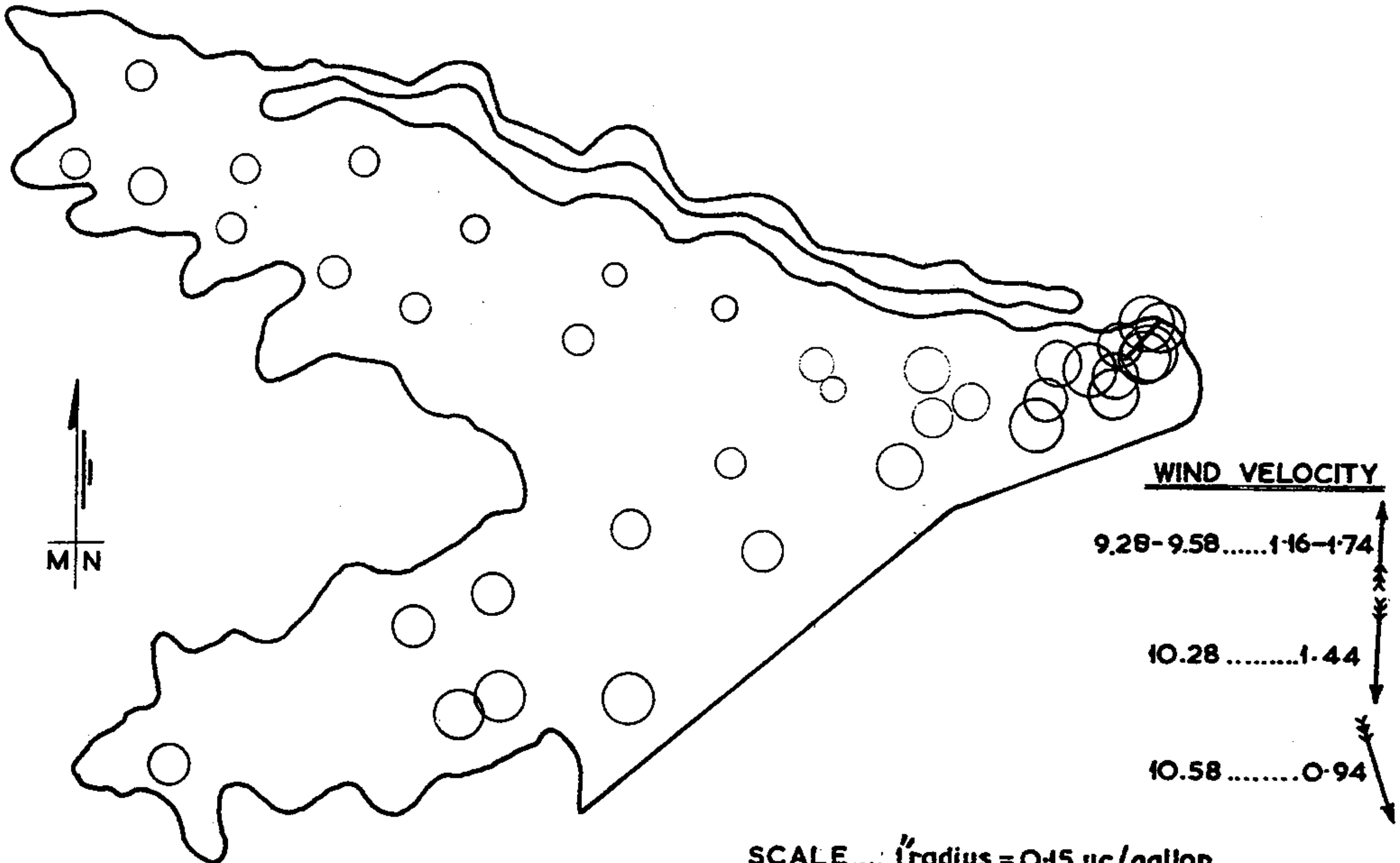
Fig. 13 FIRST DAY... NOON – 2.00 p.m.

P9



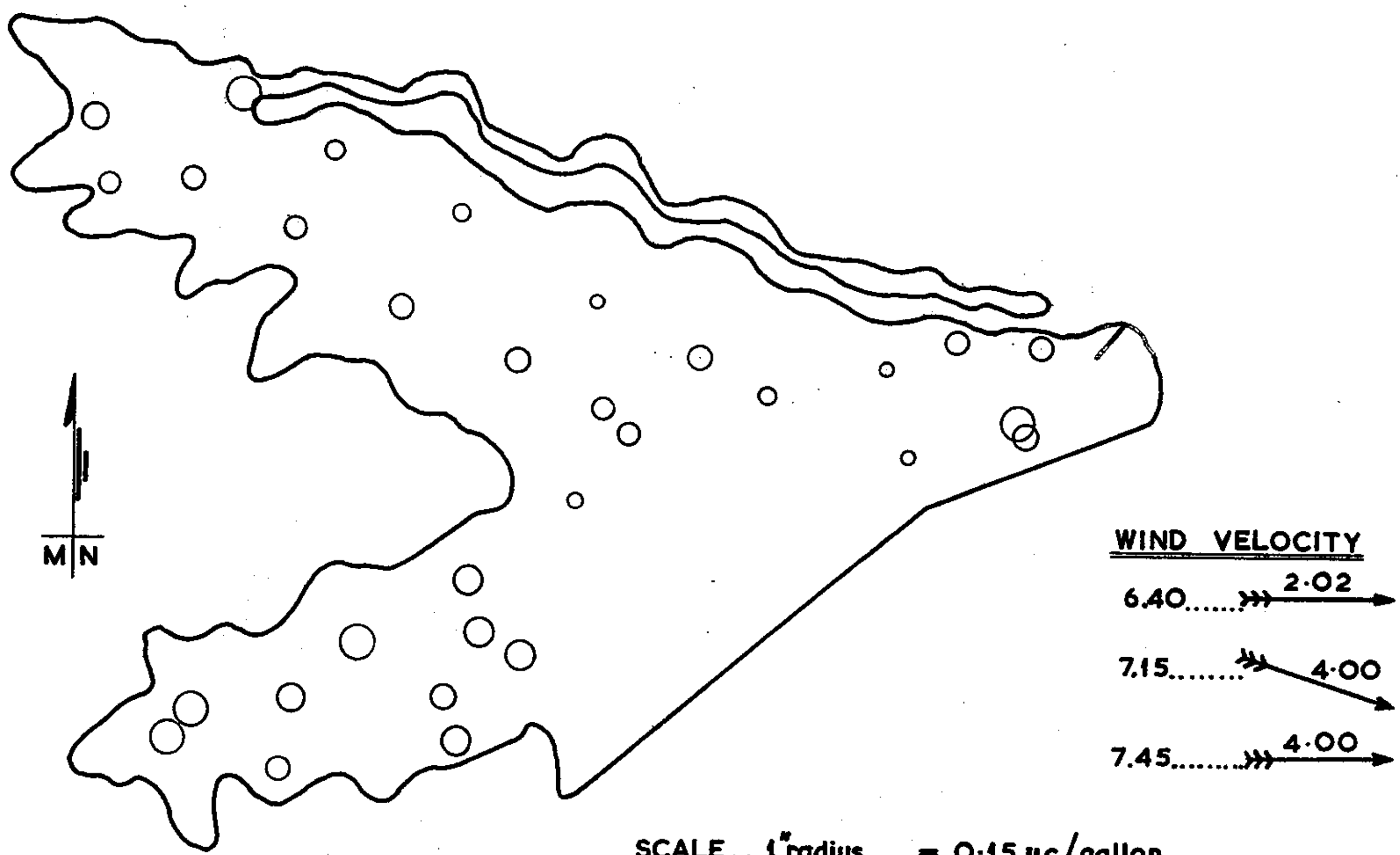
SCALE.... 1" radius = 0·15 μc/gallon

Fig.14 FIRST DAY...3.00-5.00 p.m.



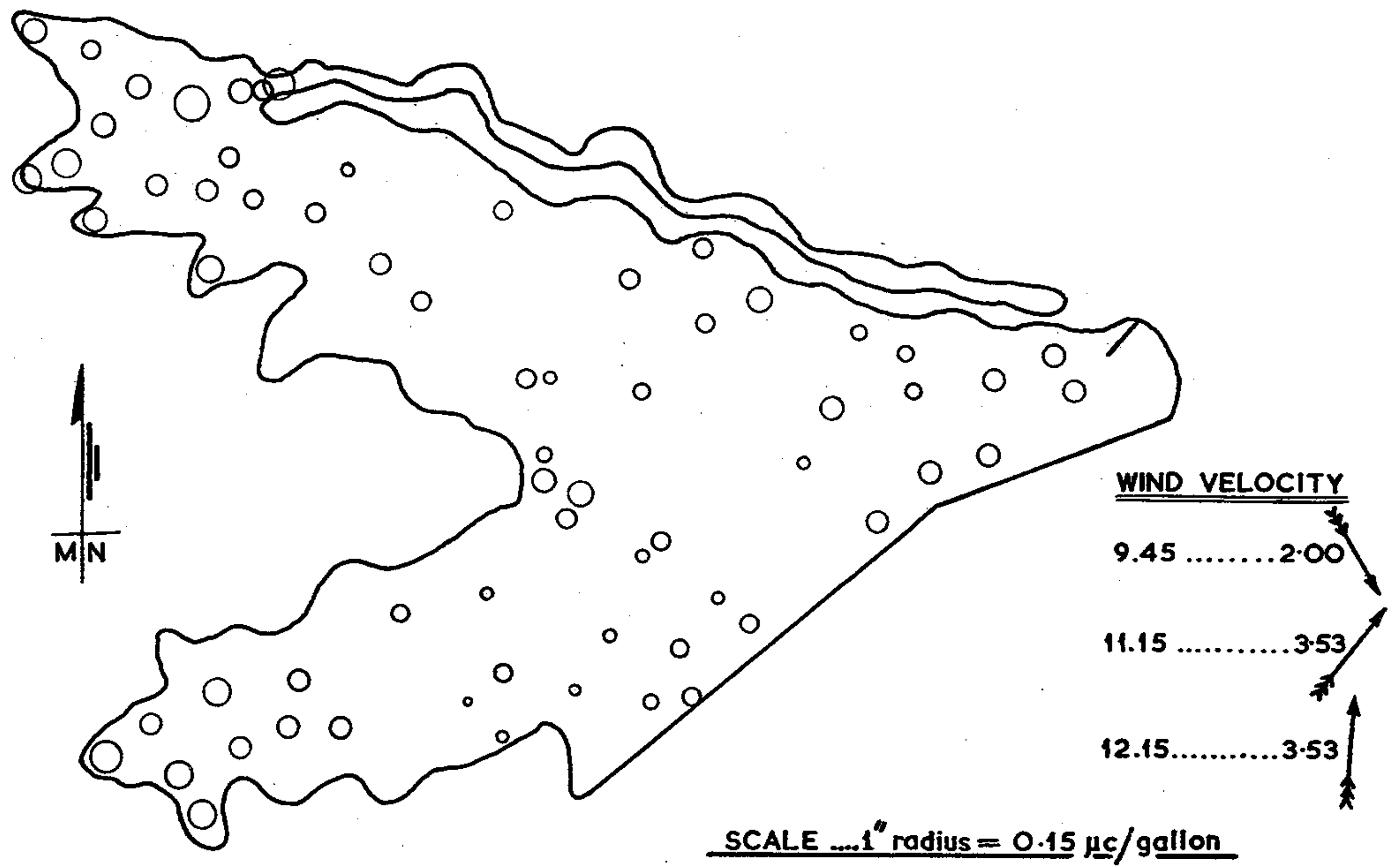
SCALE.... 1" radius = 0·15 μc/gallon

Fig. 15 FIRST DAY... 9.00–11.00 p.m.



SCALE .... 1" radius = 0·15 μc/gallon

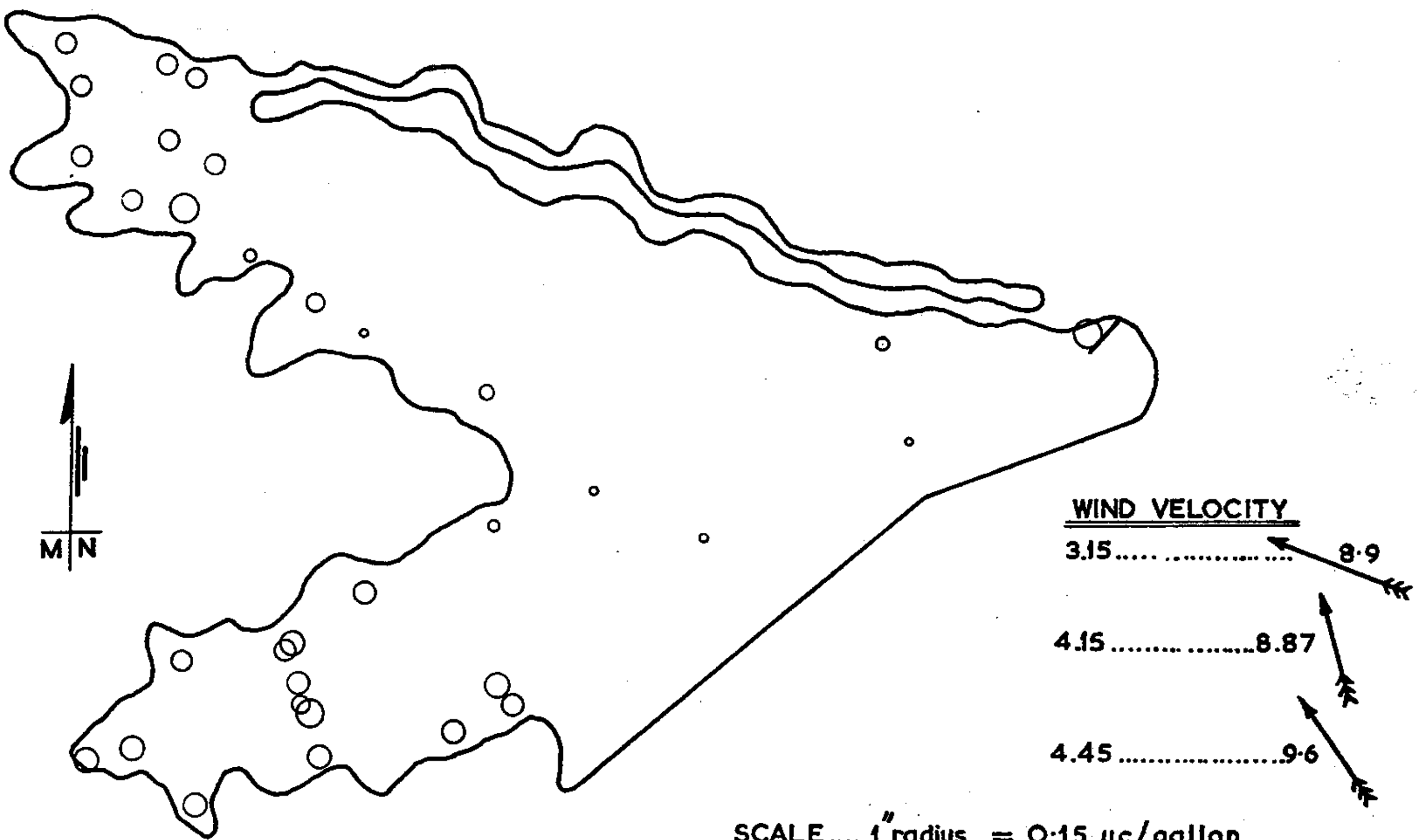
Fig.16 SECOND DAY ... 6.00 – 8.00 a.m.



SCALE ....1" radius = 0·15 μc/gallon

Fig.17 SECOND DAY...10.00 a.m — NOON

P9



SCALE.... 1" radius = 0·15 μc/gallon

Fig.18 SECOND DAY... 3.30 – 5.45 p.m.

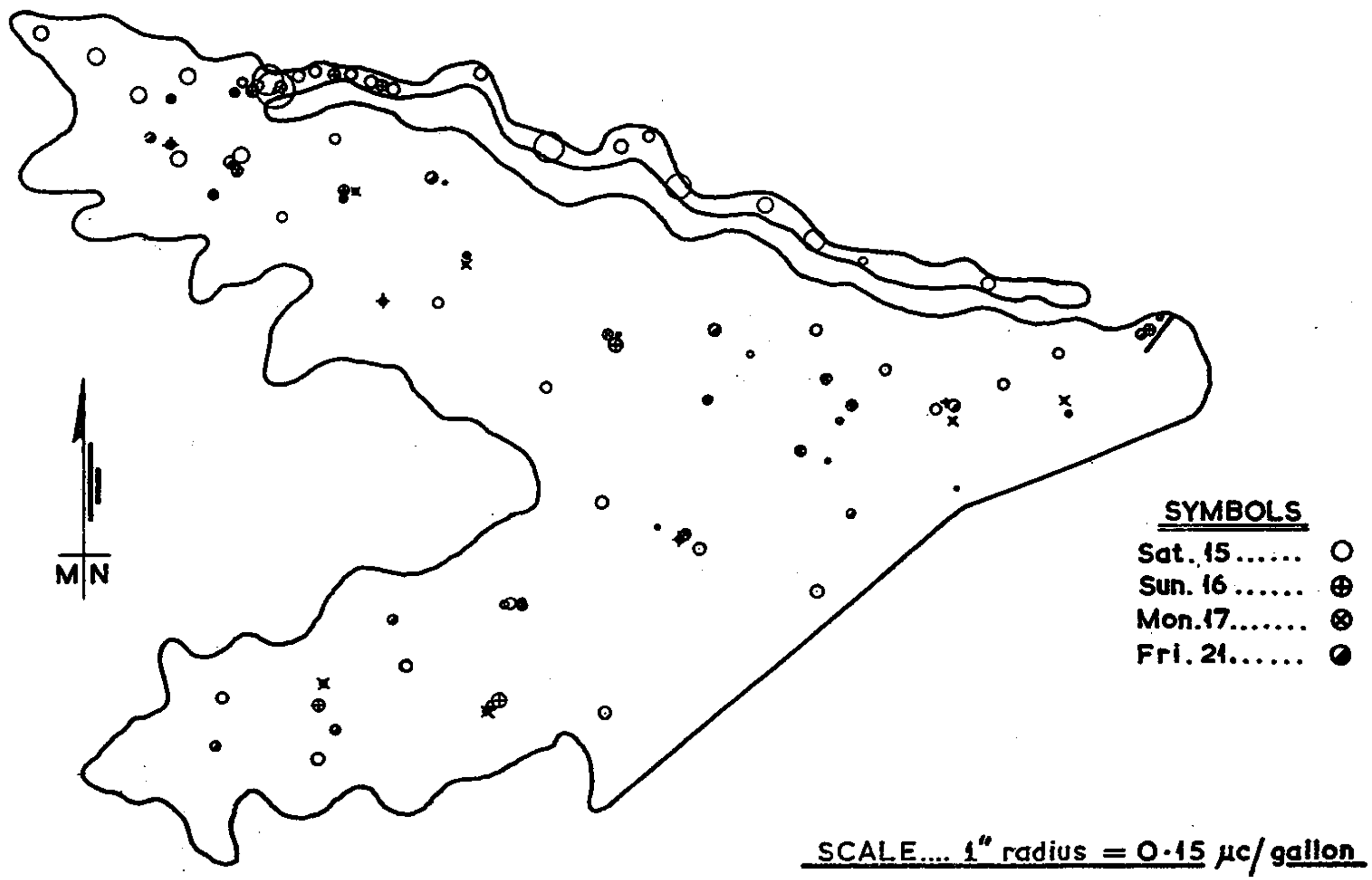
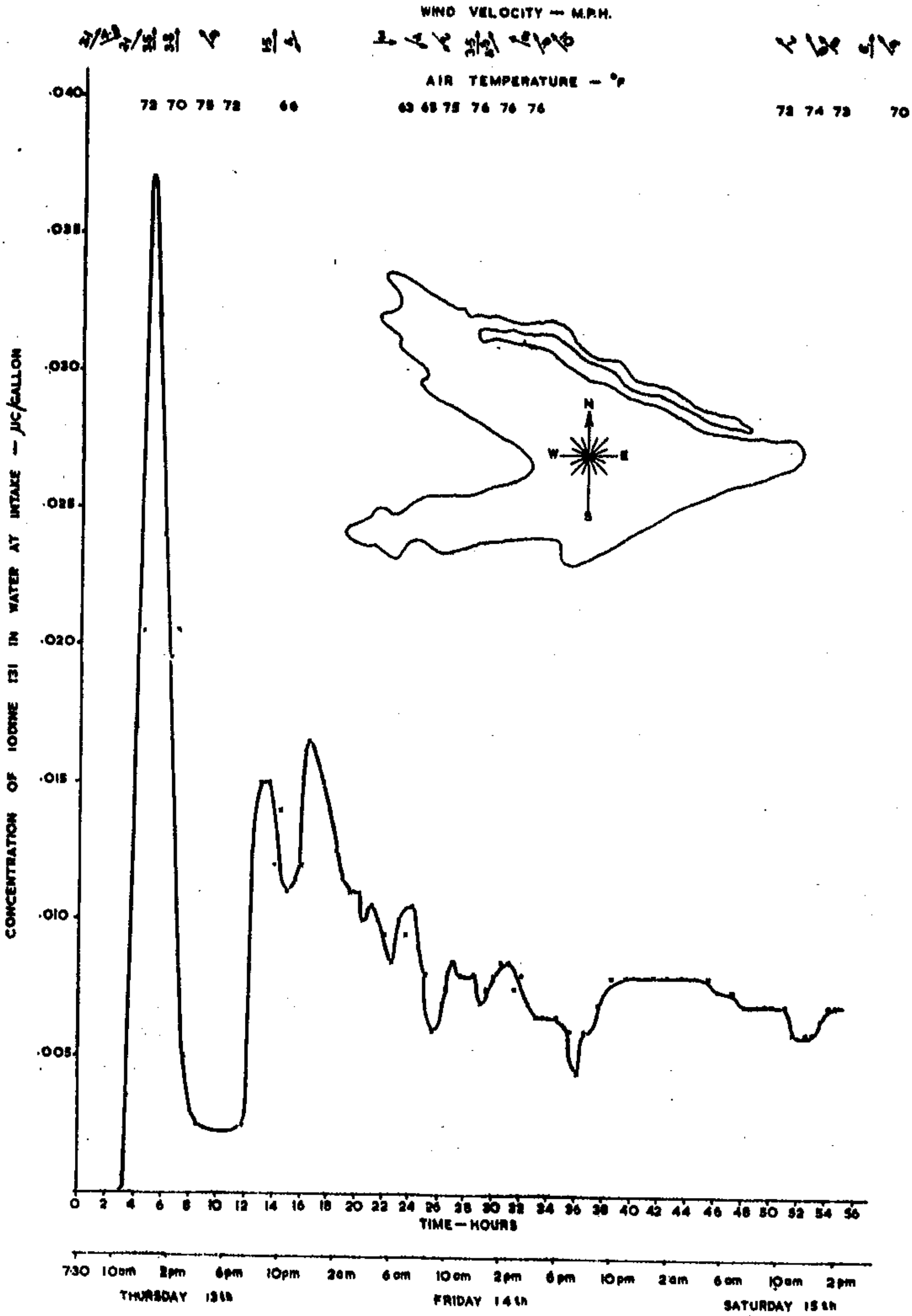


Fig. 19 THIRD, FOURTH, FIFTH AND NINTH DAYS



WIND VELOCITY — M.P.H.
AIR TEMPERATURE — °F
72 70 75 72 66
63 68 72 74 76 76
72 74 73 70
.040
.035
.030
.025
.020
.015
.010
.005
CONCENTRATION OF IODINE 131 IN WATER AT INTAKE — μc/GALLON
N
W
E
S
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56
TIME—HOURS
7:30 10am 2pm 6pm 10pm 2am 6am 10am 2pm 6pm 10pm 2am 6am 10am 2pm
THURSDAY 13th
FRIDAY 14th
SATURDAY 15th

FIG. 20

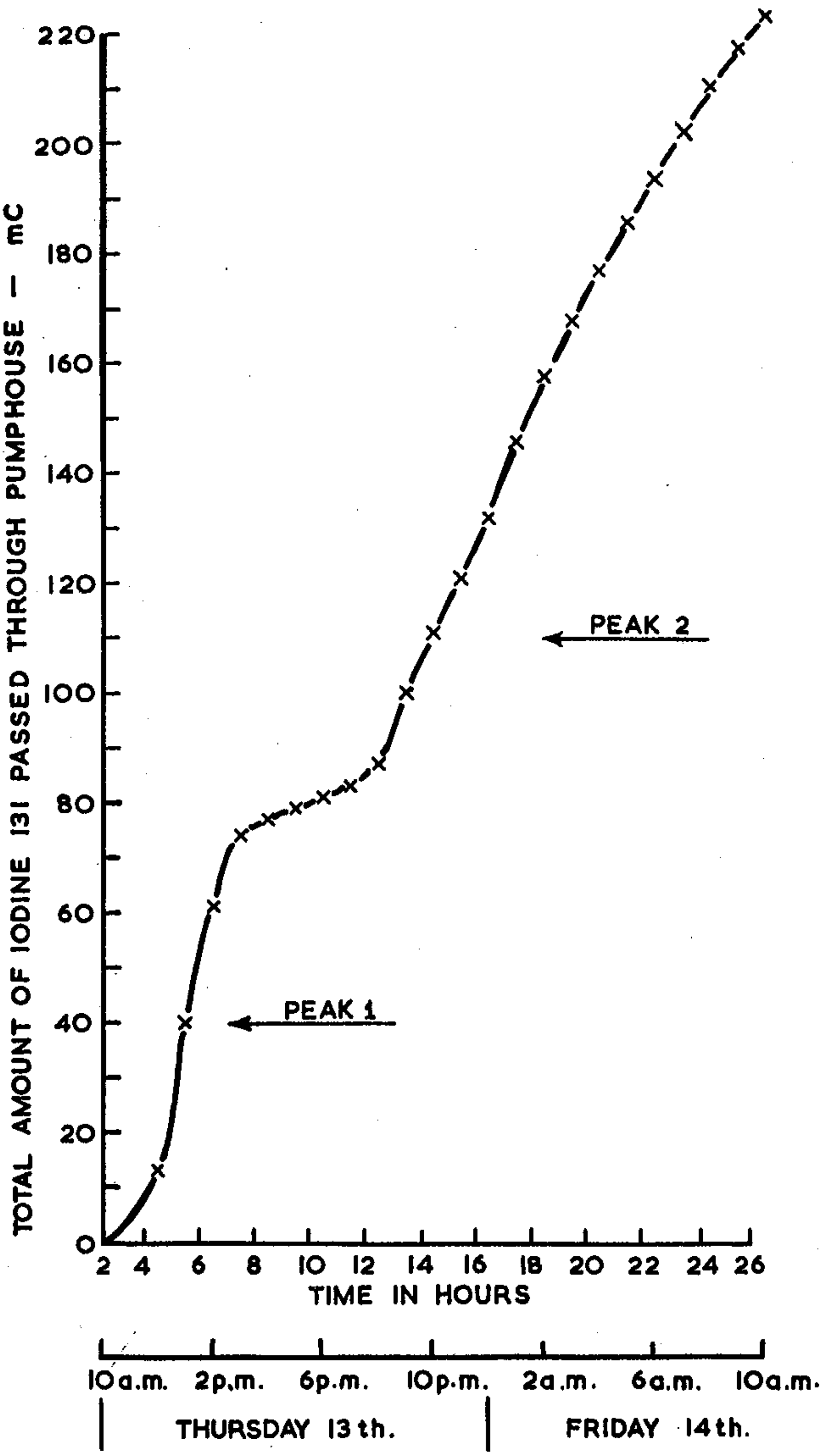

TOTAL AMOUNT OF IODINE 131 PASSED THROUGH PUMPHOUSE — mC
220
200
180
160
140
120
100
80
60
40
20
0
PEAK 1
PEAK 2
2 4 6 8 10 12 14 16 18 20 22 24 26
TIME IN HOURS
10a.m. 2p.m. 6p.m. 10p.m. 2a.m. 6a.m. 10a.m.
THURSDAY 13th.
FRIDAY 14th.

FIG. 21

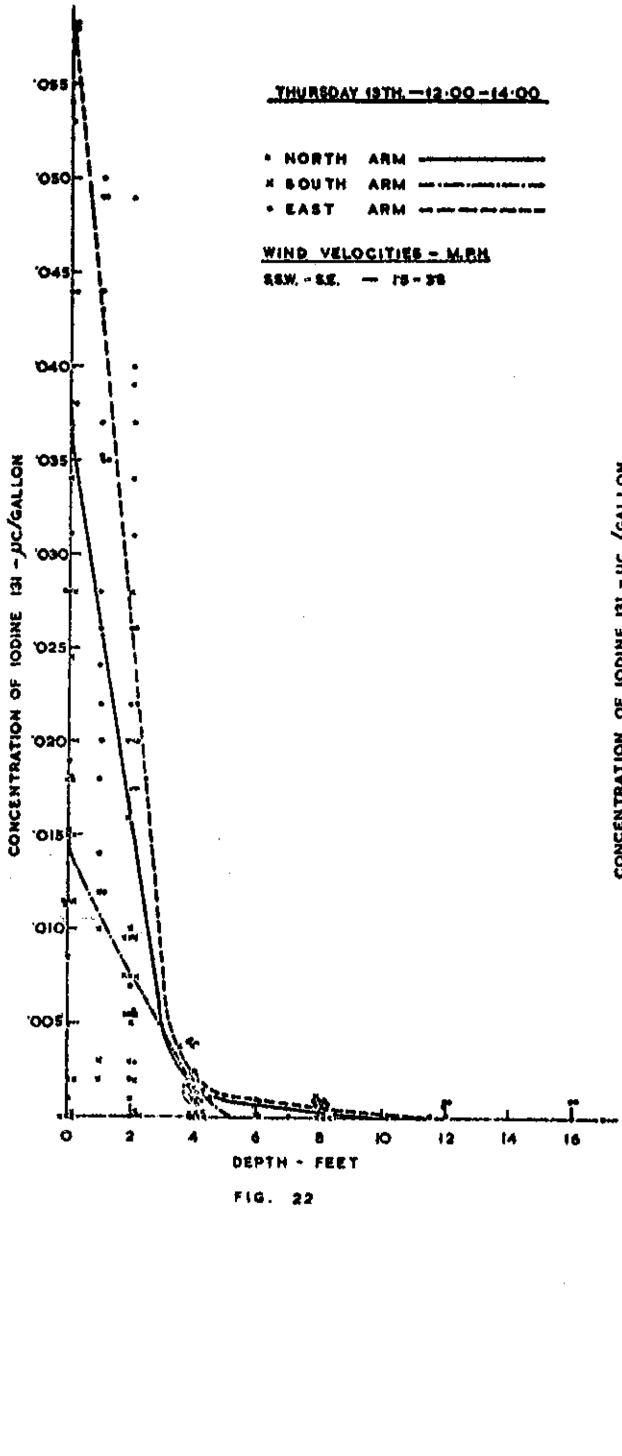

THURSDAY 13TH. — 12·00 – 14·00
• NORTH ARM
× SOUTH ARM
• EAST ARM
WIND VELOCITIES – M.P.H.
S.S.W. – S.E.
CONCENTRATION OF IODINE 131 – μc/GALLON
DEPTH – FEET

FIG. 22

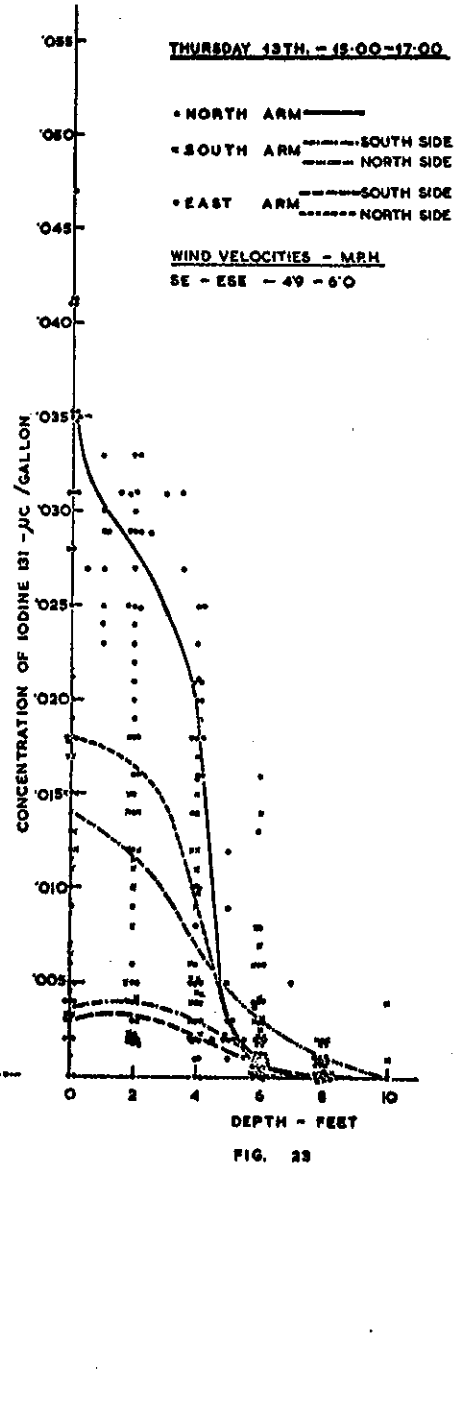

THURSDAY 13TH. – 15·00 – 17·00
• NORTH ARM
× SOUTH ARM SOUTH SIDE
NORTH SIDE
• EAST ARM SOUTH SIDE
NORTH SIDE
WIND VELOCITIES – M.P.H
SE – ESE – 4·9 – 6·0
CONCENTRATION OF IODINE 131 – μc /GALLON
DEPTH – FEET

FIG. 23

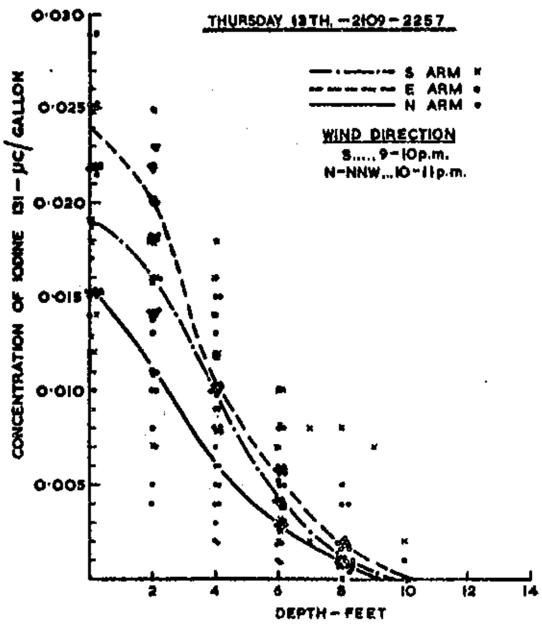


FIG. 24

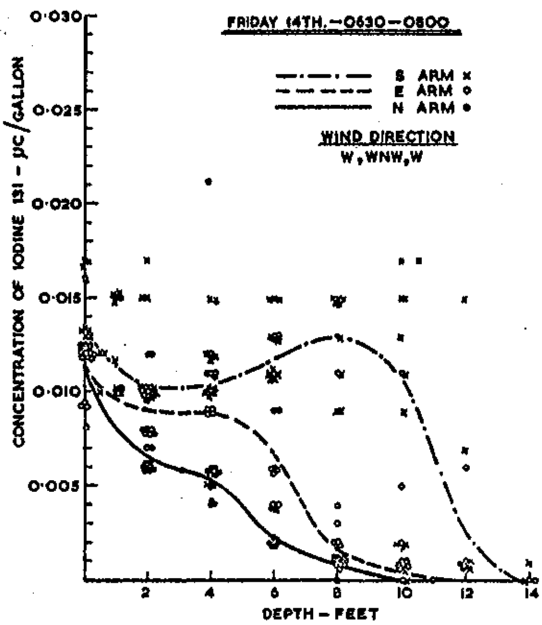


FIG. 25

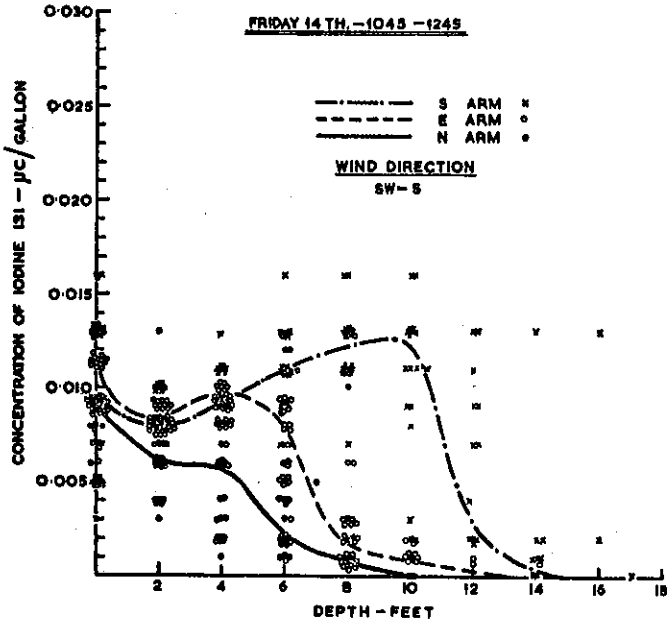


FIG. 26

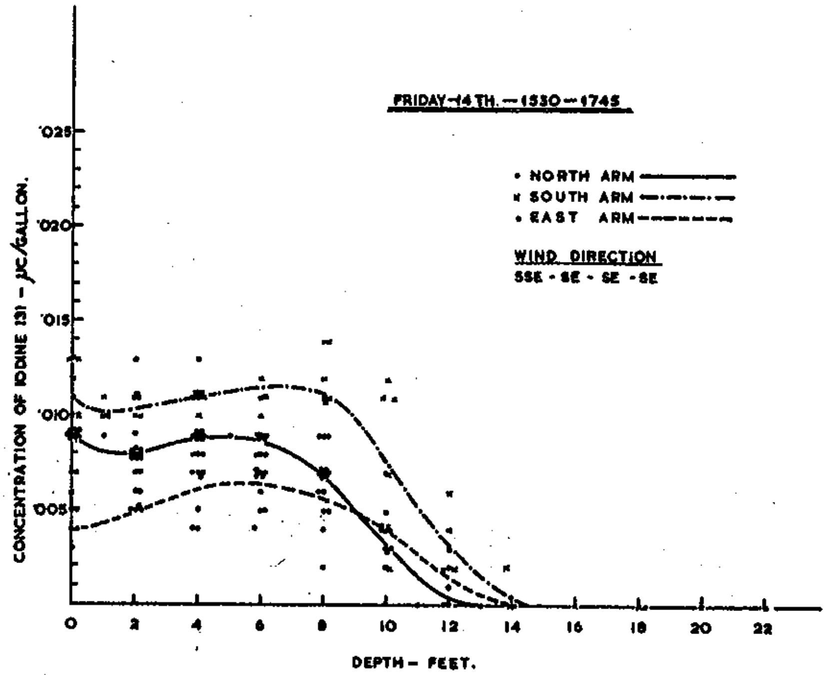

FRIDAY 14 TH. — 1530 — 1745
·025
·020
·015
·010
·005
CONCENTRATION OF IODINE 131 - μC/GALLON.
NORTH ARM
SOUTH ARM
EAST ARM
WIND DIRECTION
SSE - SE - SE - SE
0
2
4
6
8
10
12
14
16
18
20
22
DEPTH – FEET.

FIG. 27

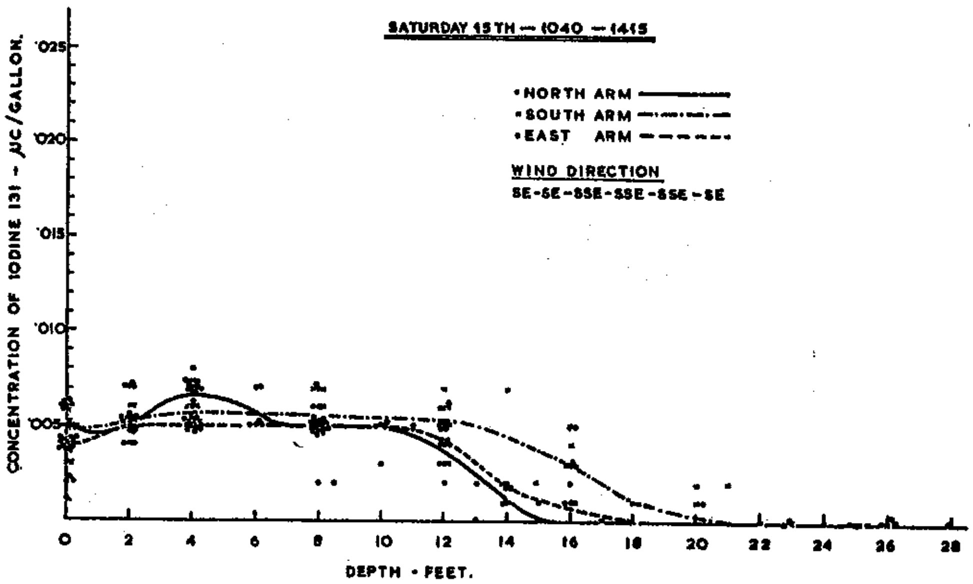

SATURDAY 15 TH — 1040 — 1415
·025
·020
·015
·010
·005
CONCENTRATION OF IODINE 131 - μC/GALLON.
NORTH ARM
SOUTH ARM
EAST ARM
WIND DIRECTION
SE-SE-SSE-SSE-SSE-SE
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
DEPTH - FEET.

FIG. 28

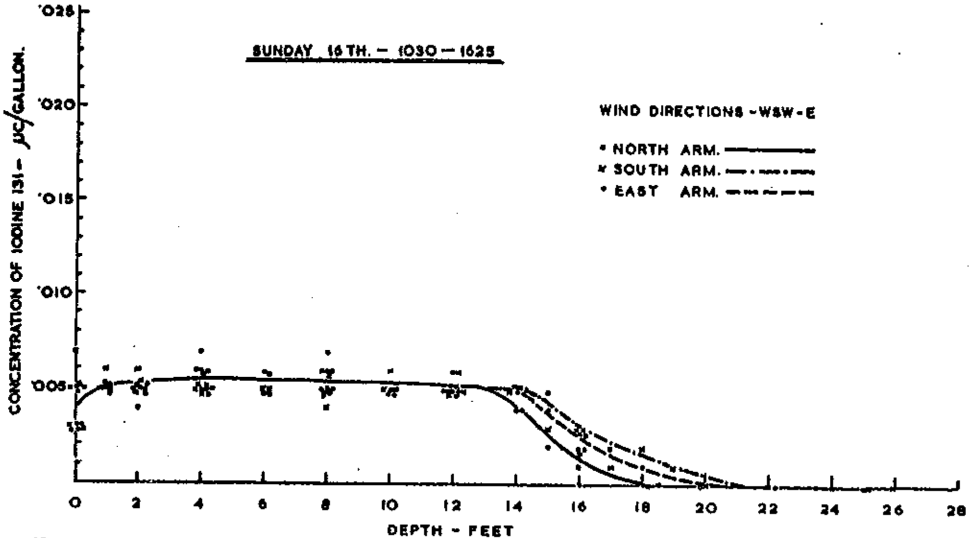


FIG. 29

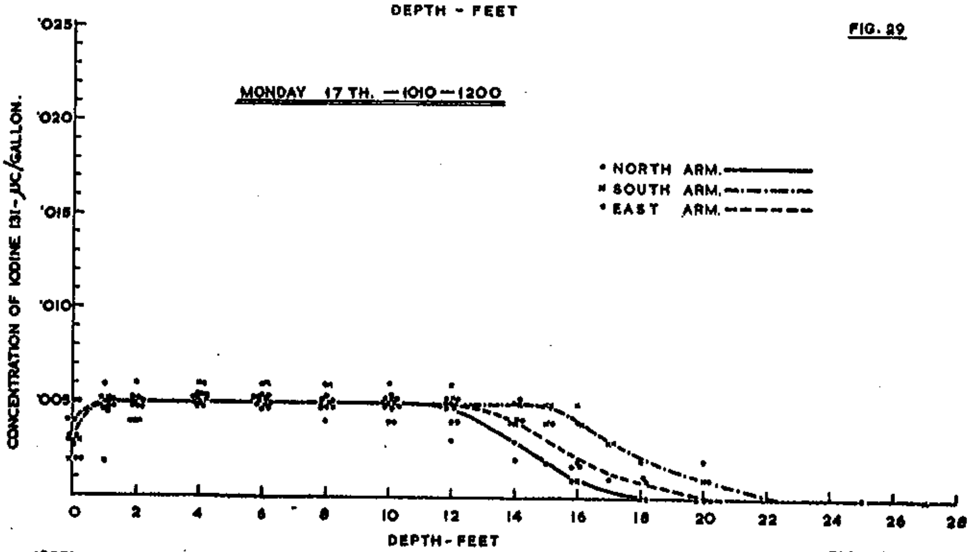


FIG. 30

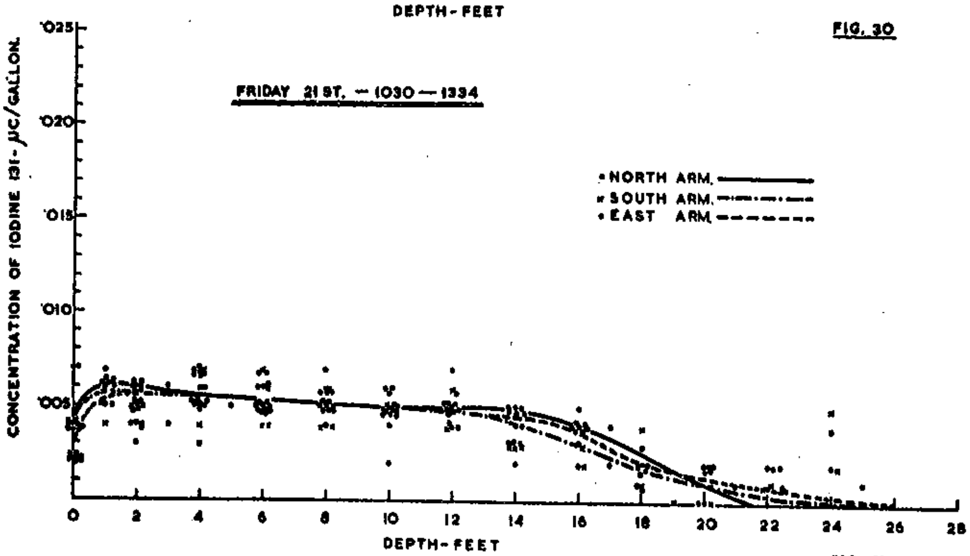


FIG. 31

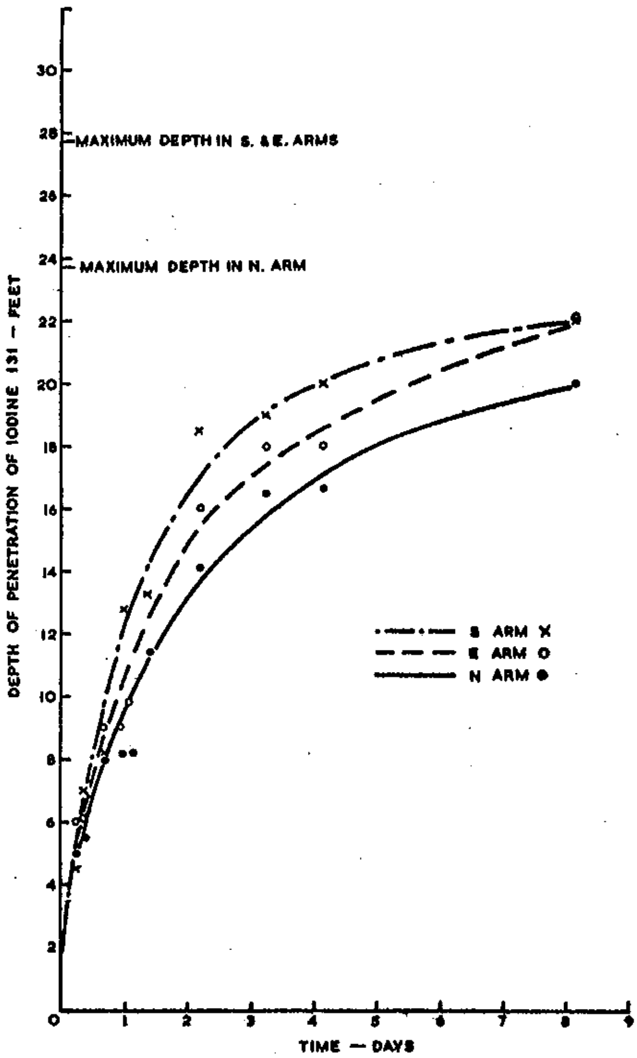
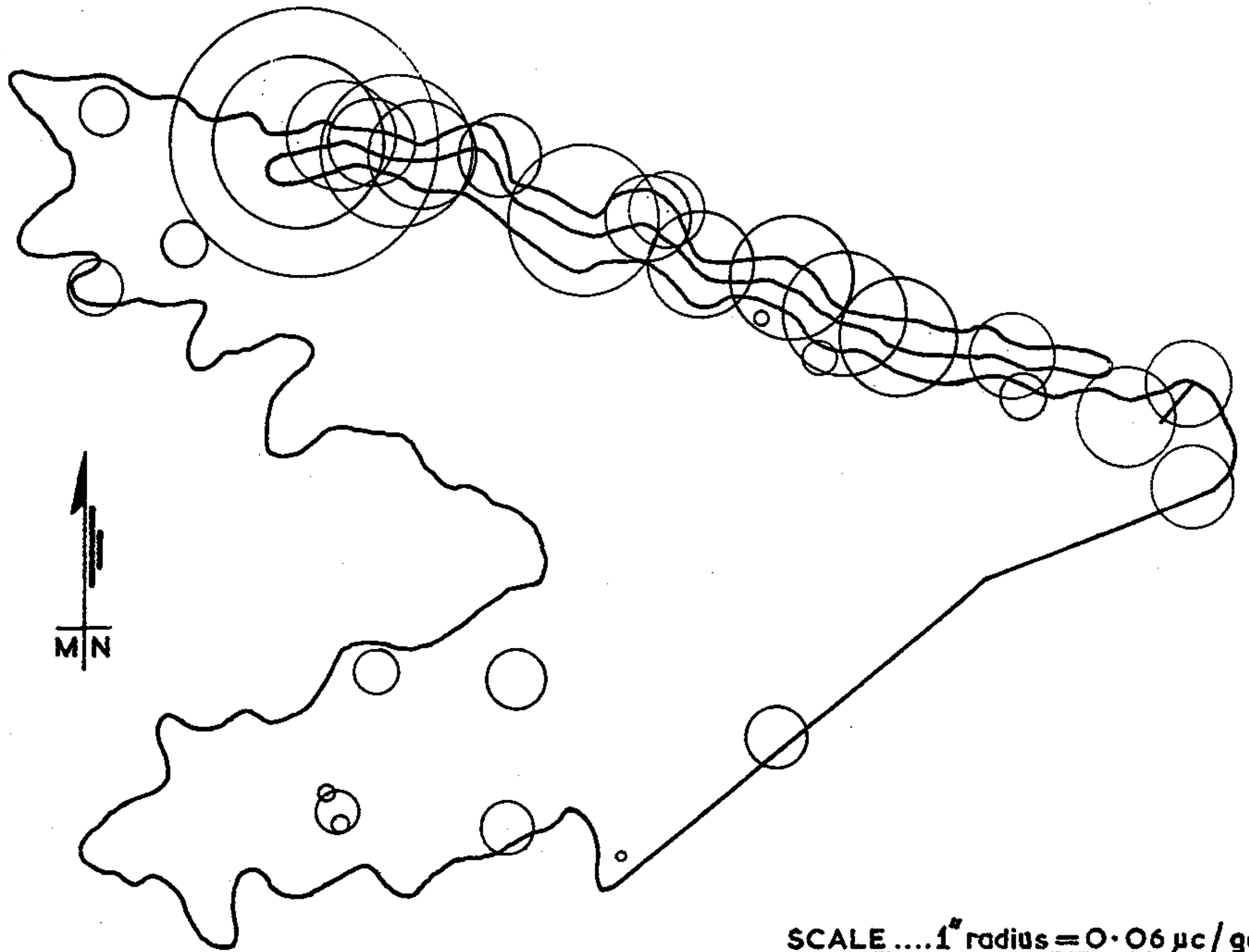

MAXIMUM DEPTH IN S. & E. ARMS
MAXIMUM DEPTH IN N. ARM
DEPTH OF PENETRATION OF IODINE 131 — FEET
TIME — DAYS
S ARM X
E ARM O
N ARM ●

FIG. 32



SCALE ....1" radius = 0·06 μc/gallon

Fig. 33 HIGH READINGS ON BED OF POND