

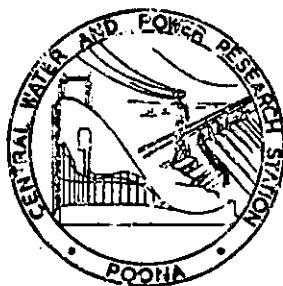
USE OF RADIOACTIVE TRACER FOR THE STUDY OF SEDIMENT MOVEMENT OFF BOMBAY HARBOUR

by

M G Hiranandani

and

C V Gole



Technical Memorandum I

June 1960

GOVERNMENT OF INDIA
CENTRAL WATER AND POWER RESEARCH STATION
Poona, India

India, Central Water and Power Research Station, Poona
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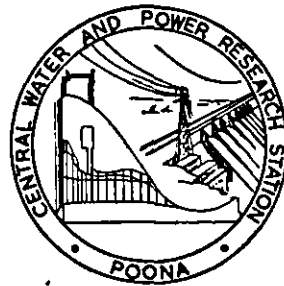
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PREFACE

Sediment movement due to tidal currents and waves is a subject of great interest to engineers, especially in connection with the improvement of navigational facilities. Several methods are known for detecting and studying it in action like the petrographic assays by sampling, etc. But they are all rather time-consuming and tedious, and as such not quite satisfactory.

With the advent of nuclear reactors in recent years and the development in detection technique, the use of radio-active isotopes as tracers has become common. In the course of the last decade their use has been extended to simulate silt movement on sea bed. The technique has since been fully explored but the method of its application remains yet to be perfected. The present note describes the relative merits of some different applications of the technique as availed in the experiment conducted off the Bombay Harbour.

The injection device was kept similar to that used in the Thames experiment except that the injector was supported in an aluminium skirt which was lowered on the sea bed. The arrangement enabled deposition of the tracer under gravity while the injector was in a vertical position. The injector was opened remotely by using compressed air actuator which device was found very satisfactory in its function.

Grinding the scandium glass was done with a vertical ball mill, as the Atomic Energy Establishment, Trombay who conducted the operations were confident of the method for yielding the desired accurate

size gradation. Eight G M Counters(type G24H) were used for detection. Experience with this type of counters has been rather confusing. During the course of the experiment, it was sometimes difficult to detect a fault in any one of them till they were checked aboard the ship by means of a standard source, at the end of the day's work. It is hence advisable to have less number of tubes, each having a more cathode area so that a fault in any of the tubes during detection becomes conspicuous on the recording unit.

The Scandium glass used for the experiment, conglomerated during its transport after irradiation from UK to India. This affected the first injection and special means had to be devised to conduct the second injection.

Three ft tongs were used for handling the active material. They were easier to manipulate than longer tongs. Persons handling the material got an activity dose of less than 20 mr for each batch of 7-8 curies. Atomic Energy Establishment, Trombay, feels that such tongs can be used for activities as high as 30 curies.

The tracer injected NW of the Malabar point spread in an area of 24.1 sq km(15 sq miles). In this area, rock outcrops frequently hindered the tracking. During the initial stages of the experiment, tracking had to be stopped when such rock outcrops snapped the connections to the rate-meter. For subsequent trackings more care had to be taken and a spare detector unit was also prepared.

Besides the confirmatory results obtained, the experiment has been useful in training personnel for the solution of similar problems by the use of Radio Isotope Method.

It has helped in clearing bottlenecks and solving difficulties

in the design and operation of equipment, improvements in and calibration of instrumentation required for injection and tracking.

A 16 mm coloured cine film has been taken of the entire operation.

Since this experiment, facilities are available for preparation of Radio Isotopes in India.

ACKNOWLEDGEMENTS

The three organisations of the Hydraulic Research Station, UK, the Atomic Energy Establishment Trombay and the Bombay Port Trust, who all collaborated with the CWPRS in their respective specialized fields, contributed very largely towards the successful completion of the experiment. C Taylor, V K Iya and A C Eapen of the AEET facilitated fabrication of the injection apparatus, detector unit and the crushing of glass; M J Crickmore of the HRS, UK conducted the experiment in the initial stages; and the AERE, Harwell, irradiated the glass; S B Dalal, R N Vinekar and A V D'Souza of the BPT rendered help at all stages.

The financial sanction kindly accorded by L T Gholap, Chairman, BPT greatly encouraged the experiment.

Along with the different officers in the CWPRS who participated in the experimental and the analytical work B D Kolhe bore the full responsibility of the experiment in the later stages; A S Apte, S P Kulkarni, G V Rao, B C Deb and S T Chaudhari all rendered valuable services. The members of the Field Survey Party most ungrudgingly put in long hours of work under trying conditions.

USE OF RADIOACTIVE TRACER FOR STUDY OF SEDIMENT MOVEMENT OFF BOMBAY HARBOUR

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As a result of silt brought by the rivers joining the Bombay Harbour basin and the littoral drift the harbour is gradually silting at an approximate rate of 1.2 cm (.04 ft) per year as seen from the surveys of the last 100 years. Depths in the harbour have reduced by 1.2 m to 1.5 m (4 to 5 ft) and have thus limited the draughts of vessels entering the harbour at any stage of tide to 9 m (30 ft). With the construction of the Oil Terminal at Butcher Island, oil tankers of 10.2 m (34 ft) enter the harbour. The present channel along the valley in the centre of the basin is not deep enough and the oil tankers have to wait for a favourable tide. The Bombay Port Trust have accordingly proposed a programme to dredge a channel to a depth 10.5 m (35 ft) below LW, extending upto Butcher Island. The proposed channel will have a width of 1805 m (6000 ft) at the entrance gradually reducing to 452 m (1500 ft) for the rest of the length (fig 1).

Hydraulic model studies were conducted at the CWPRS for selecting a suitable spoil ground for dumping the silt dredged from the proposed channel. The studies indicated that no such ground could be found inside the harbour basin. Due to the pattern of flood and ebb currents obtaining in the harbour, silt dumped in the harbour will be put into recirculation to be deposited finally in the deeper channel. Thus no site inside the harbour was found suitable as a spoil ground unless it was protected by bunds. It was, therefore, necessary

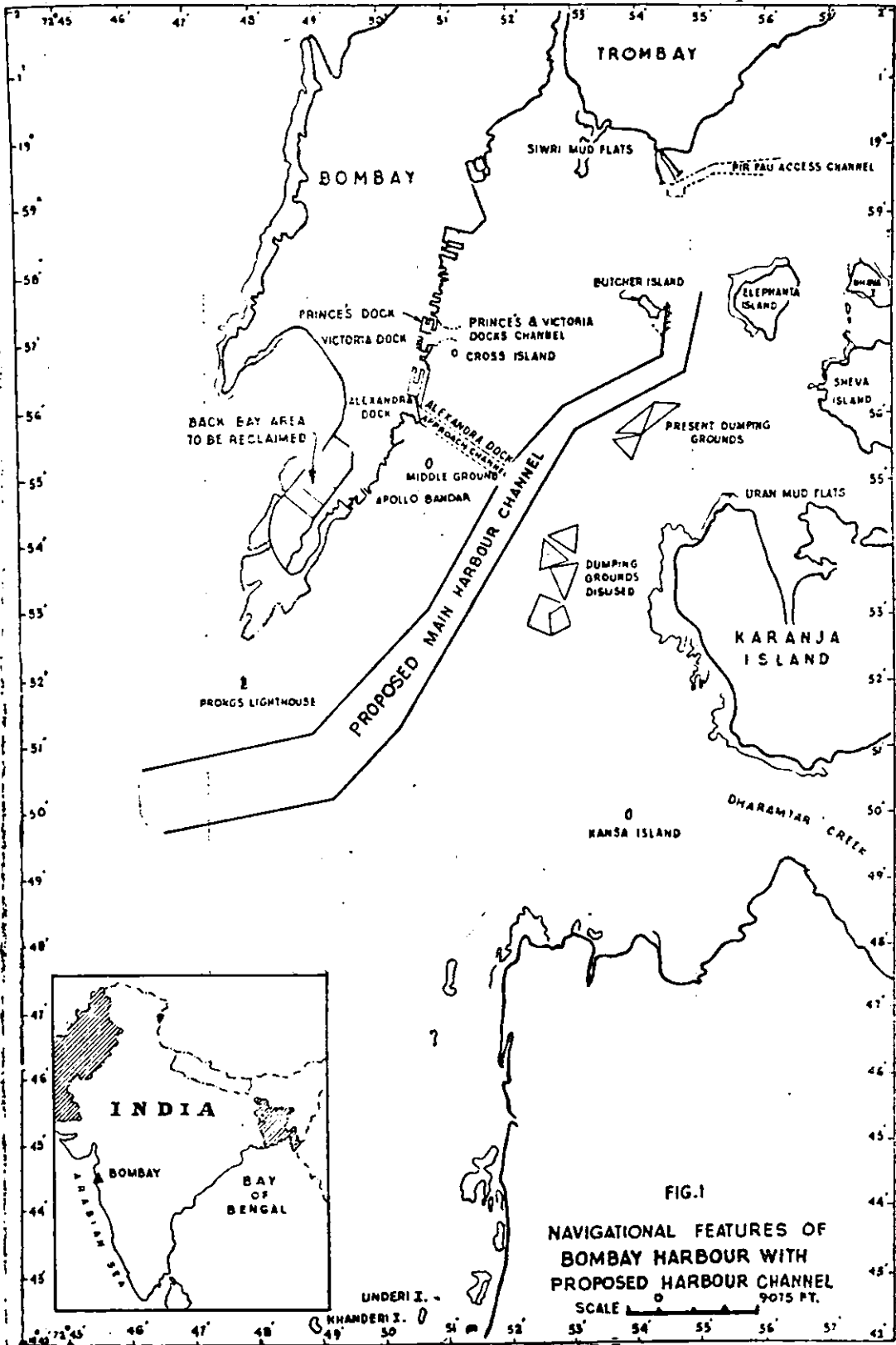
to seek a location outside the harbour basin either north or south of the harbour entrance. The areas to the south of the harbour entrance were also found unsuitable as the currents over there tend to transport the material back into the harbour basin. The only choice of a location for the dumping ground was thus to the north of the harbour entrance. In this area flood and ebb currents are almost parallel to the shore, but in the region opposite the Backbay(fig 2), the tidal currents are rotary and will tend to transport the material towards the harbour entrance. It was necessary, therefore, to go further north. The experiments indicated that in the areas NW of Malabar Point the material dumped beyond 9 m(30 ft) contour was not likely to travel towards the harbour(fig 3). These tests were conducted with the waves approaching from WSW which is the dominant direction.

TRACER STUDY

Sediment transport on the sea bed near the Bombay Harbour is a complex phenomenon caused mainly by periodic forces like tides and waves. As mentioned above, model tests for choosing spoil ground NW of Malabar point were done with waves from WSW with a consequent bias for transporting material northwards away from the harbour entrance.

Since the above results were based on meagre data of velocity observations, confirmatory evidence was thought desirable before starting the capital dredging programme requiring an outlay of Rs 120 millions.

The waves approach from W and NW from January to middle of May every year(fig 4). This direction will have a consequent bias towards south for the movement of bed material. In view of this, it was deci-



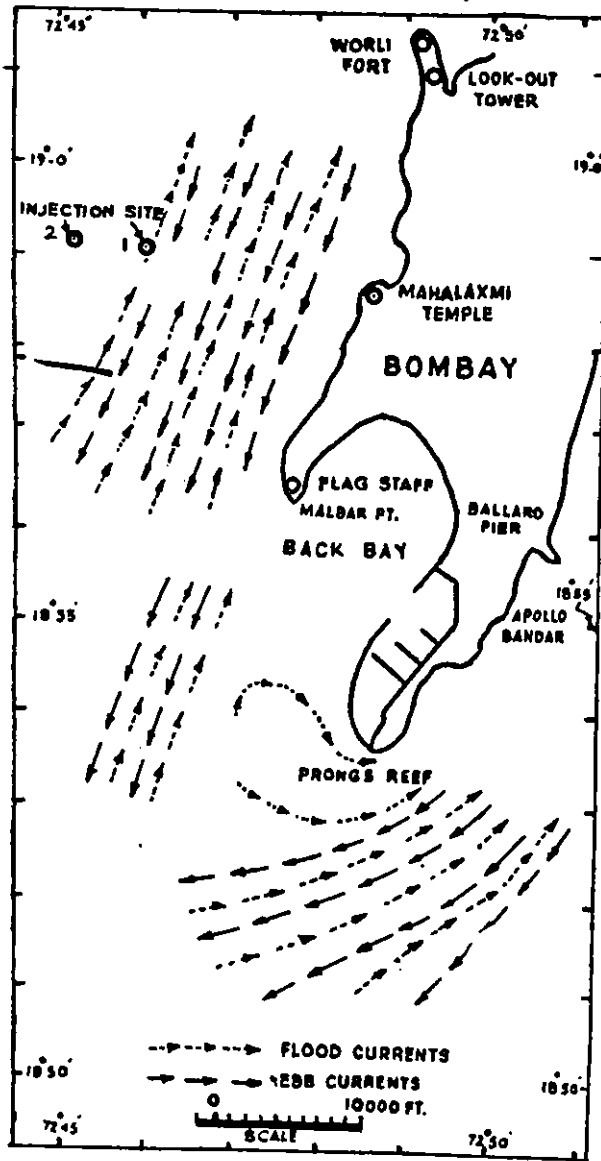


Fig 2 : Tidal currents in the working area

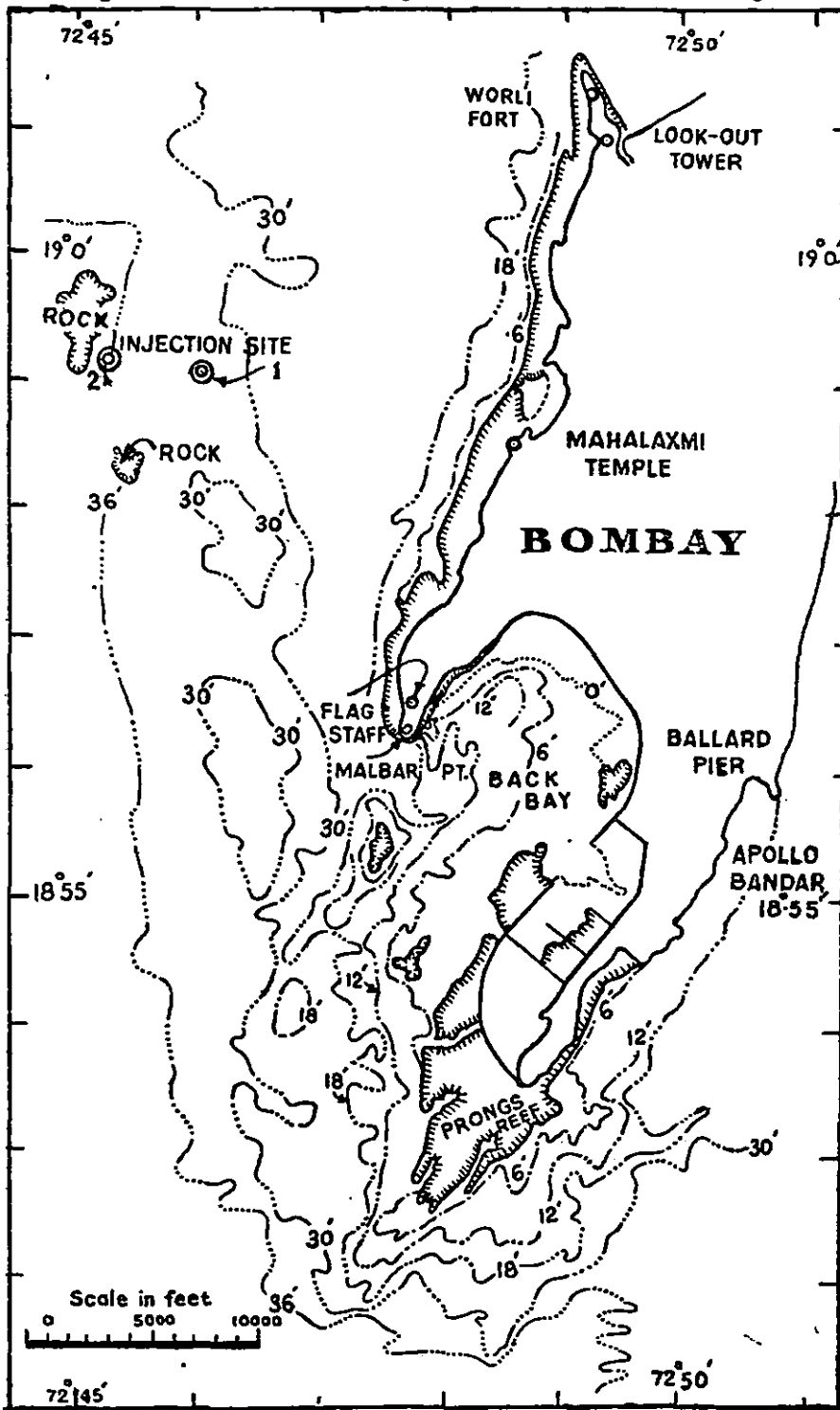
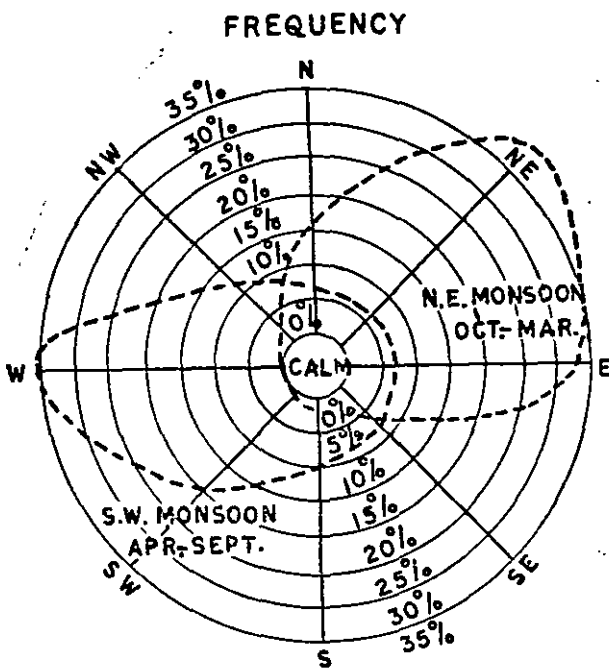
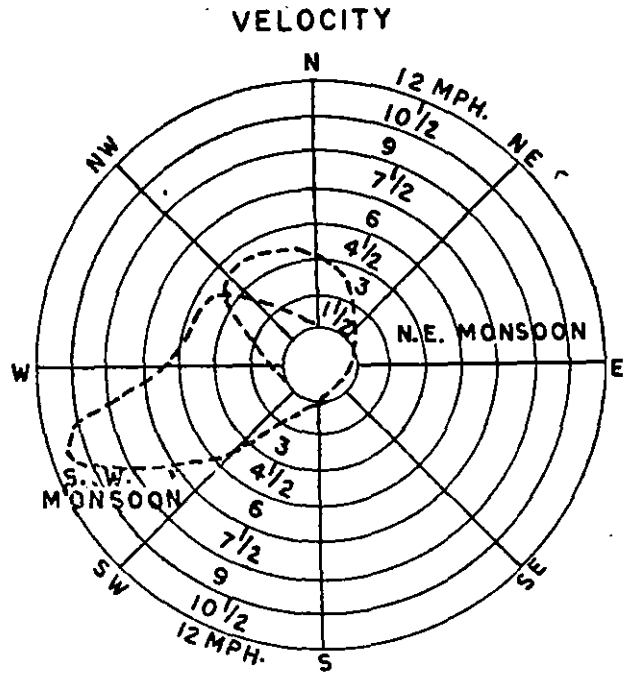


Fig 3 : Plan of working area



SCALE GIVES MEAN PERCENTAGE FREQUENCY OF THE WIND FOR A MONSOON PERIOD



SCALE GIVES MEAN MONTHLY VELOCITY IN MILES PER HOUR

The maximum daily velocity is approximately $1\frac{1}{2}$ times the monthly mean
 The maximum hourly velocity is approximately $2\frac{1}{2}$ times the monthly mean
 The frequency diagram is based on readings over a 12 year period
 The velocity diagram is based on readings over a 53 year period

Fig 4 : Wind diagrams for frequency and velocity

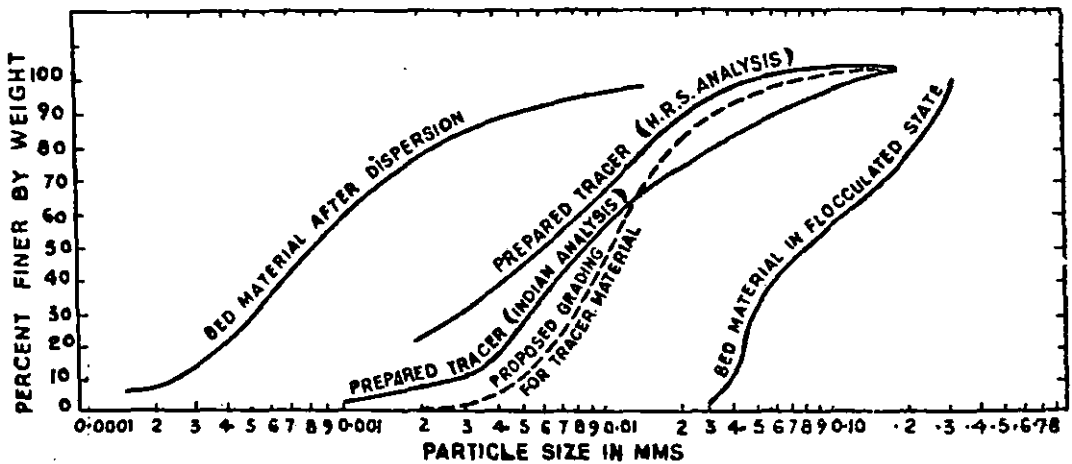


Fig 5 : Size distribution curves for the bed material and radioactive tracer

ded to carry out the tracer study during March-May 1959.

TRACER MATERIAL

In order that the tracer material should have the same transport characteristics as the sediment in situ, the specific gravity, grain size distribution and the nature of surface of the tracer particles should be similar to the corresponding properties of the natural sediment. Other practical considerations governing the choice of the tracer material were

- i it should have half-life long enough to remain traceable for a considerable duration, and
- ii it should emit sufficiently hard gamma rays.

Scandium 46 with a half life of 85 days and emitting 2 kinds of gamma rays of 1.12 MeV and 0.87 MeV respectively per disintegration satisfies the two requirements.

Boron free glass has been found to be a suitable carrier for Scandium Oxide. (Boron is unsuitable as it is a strong absorber of neutrons.) The following composition of glass having a density of 2.6 against the silt density of 2.65 was chosen:

Major constituents	% by weight
Sc ₂ O ₃	1.5
SiO ₂	64.0
Na ₂ O	18.58
CaO	15.75

The above mixture was fused at 1300°C and was allowed to cool for four hours to yield 780 grams of glass. This glass was ground to obtain a size gradation representative of the natural sediment.

SIZE GRADATION

Bed material to be dredged from the Harbour as well as near the

proposed dumping ground is clayey with a very small organic component (2 percent). It obtains in the form of floccules due to salinity of the sea water and the zeta potential of the particles. As there is no standard method of finding the size distribution of the material under flocculated state the following procedure was adopted by employing Puri's siltometer in which a column of saline water 200 cm high is held in a brass tube resting on a trough.

A quantity of wet silt to yield 5 gm of dry silt was thoroughly stirred in a 40 cc sodium chloride solution of 3 percent strength and was allowed to form flocs for 24 hours. The flocculated solution was stirred and dropped in the siltometer tube, which was filled previously with a 3 percent sodium chloride solution. The silt thus dropped was collected in the bottom troughs at definite intervals. The silt samples collected were washed with 80 percent alcohol and were dried and weighed. The diameters of the different fractions were then calculated from Stokes' law assuming the specific gravity of the particles as 2.65. The actual diameter of the particles in each trough is much higher, since the specific gravity of the floc is less than 2.65 due to the presence of entrapped water. For the purpose under consideration, however, the more important characteristic is the settling velocity and not the actual size distribution of the flocculated particles.

The silt was also analysed in a dispersed state by using H_2O_2 and HCl. The inorganic clay fraction disperses to finer sizes when organic matter is removed by H_2O_2 and when calcium carbonate is removed by HCl treatment. This is seen from the curve corresponding to the dispersed state (fig 5).

For the final selection of the grading of the scandium glass the

following points were taken into consideration:

- i the glass particles, being inert, will not have an appreciable tendency to form flocs and will, therefore, settle as individual particles;
- ii due to currents and wave action a part of the flocculated silt in situ may break down to finer particles, whereas glass particles of equivalent diameter cannot dissociate and will probably move differently from silt.

It was, therefore, necessary to select a size distribution of the tracer particles intermediate to the two size distributions respectively for the flocculated and the dispersed states. Fig 5 shows the gradation curve adopted for the tracer particles. Particles of size less than 2 microns were excluded as they are likely to be thrown into suspension. To achieve this gradation, the fused glass was ground in a vertical vibrating ball mill with steel balls. The mechanical analysis of the tracer indicated a mean diameter of 11 microns. The Sc_2O_3 content was found to be 1.05 percent against its adopted value of 1.5 percent.

The graded tracer material was irradiated at AERE, Harwell, UK, for 11 weeks at a pile factor of 12, giving a total activity of 27 curies. The activated tracer was available for injection nearly 9 weeks after its removal from the pile with an attenuated activity of 16 curies (fig 6). Table 1 shows the distribution of activity in the various particle size groups of the tracer.

TABLE 1

Particle size: (microns)	Activity: :(curies):	% activity	Particle size: (microns)	Activity: :(curies):	% activity
below 1	.64	4	7 - 8	.80	5
1 - 2	.32	2	8 - 9	.64	4
2 - 3	.48	3	9 - 10	.80	5
3 - 4	.64	4	10 - 20	2.88	18
4 - 5	.96	6	20 - 30	1.25	8
5 - 6	1.44	9	30 - 40	.80	5
6 - 7	.96	6	40 & above	3.36	21
			total	16.00	

DETECTION EQUIPMENT

The detection equipment consisted of 8 GM tubes(G24H) mounted with rings of sponge rubber around them in a 60 cm(2 ft)long aluminium cartridge 12.7 cm(5 in)diameter(Photo 1). The aluminium cartridge was gripped to a water-tight brass canister by strip springs(Photo 2). The brass canister was mounted in turn in a sledge by means of springs(Photo 3). Initial runs with these mountings led to a modification of the method of suspension. The springs holding the brass canister inside the sledge were replaced by two collars of 5.1 cm x .63 cm(2 in x $\frac{1}{4}$ in)steel flats, ribbed transversely by short lengths of hosepipe.

Cable connecting the counter circuit to the ratemeter was housed in a water-tight hose 66.2 m(220 ft) long. The hose was protected by a thick rubber tubing near its junction with the sledge and was bound with coir rope to give additional protection from brushing against rock. The sledge was given a hydrofoil shape for ease of dragging on the sea bed. The weight of the sledge was made 114 kgm(250 lbs)to prevent its moving off bed. Damage to the hose pipe and to the dragline occurred occasionally, but on the whole the system worked satisfactorily.

Impulses of the counter tubes were fed to a field ratemeter(type 1368 A)which also supplied a working voltage of 380 V to the counters (Photo 4). The ratemeter scale was calibrated in millirontgen per hour (mR/hr) upto a maximum of 5 mR/hr. In the initial stages of the experiment a permanent record of the activity was kept by using a spark recorder(type 1487 A)in conjunction with the ratemeter(Photo 5).

ACCURACY

The efficiency of GM tubes is limited mostly due to the randomness of gamma radiation and is of the order of 1 percent. One way to



Photo 1



Photo 2

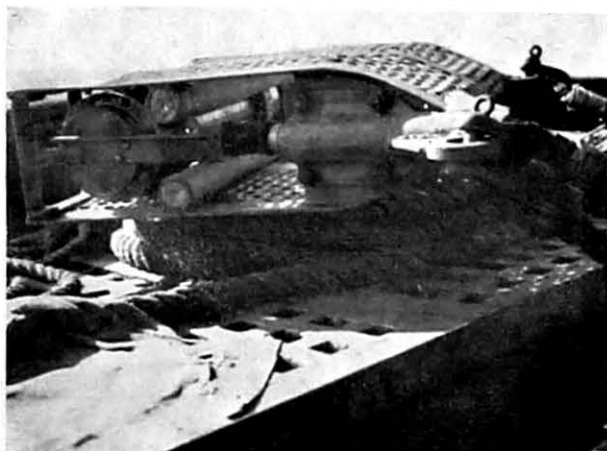


Photo 3
Sledge with detector assembly



Photo 4

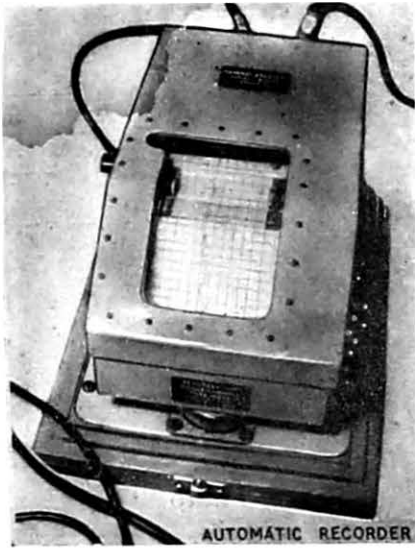


Photo 5

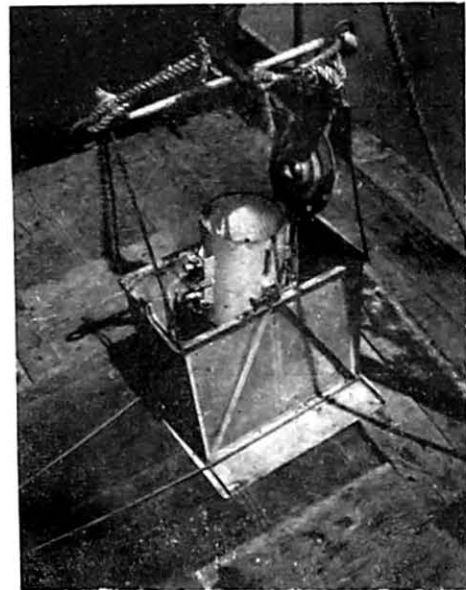


Photo 6
Injection apparatus



Photo 7
Injector being shaken for mixing
its contents.

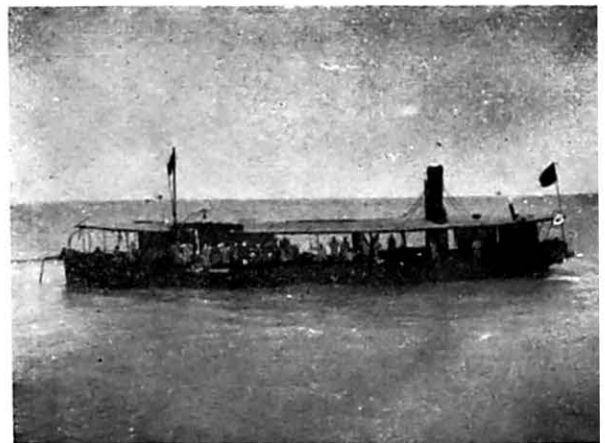


Photo 8
Screened space on ship
for handling the active material

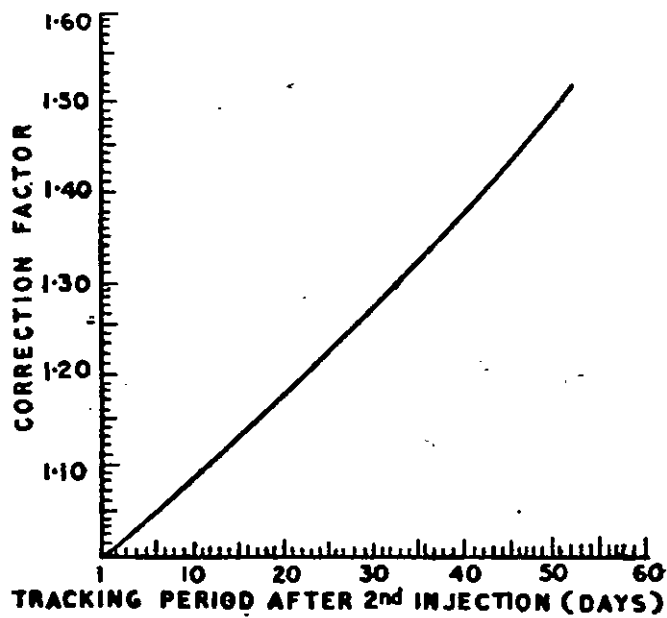
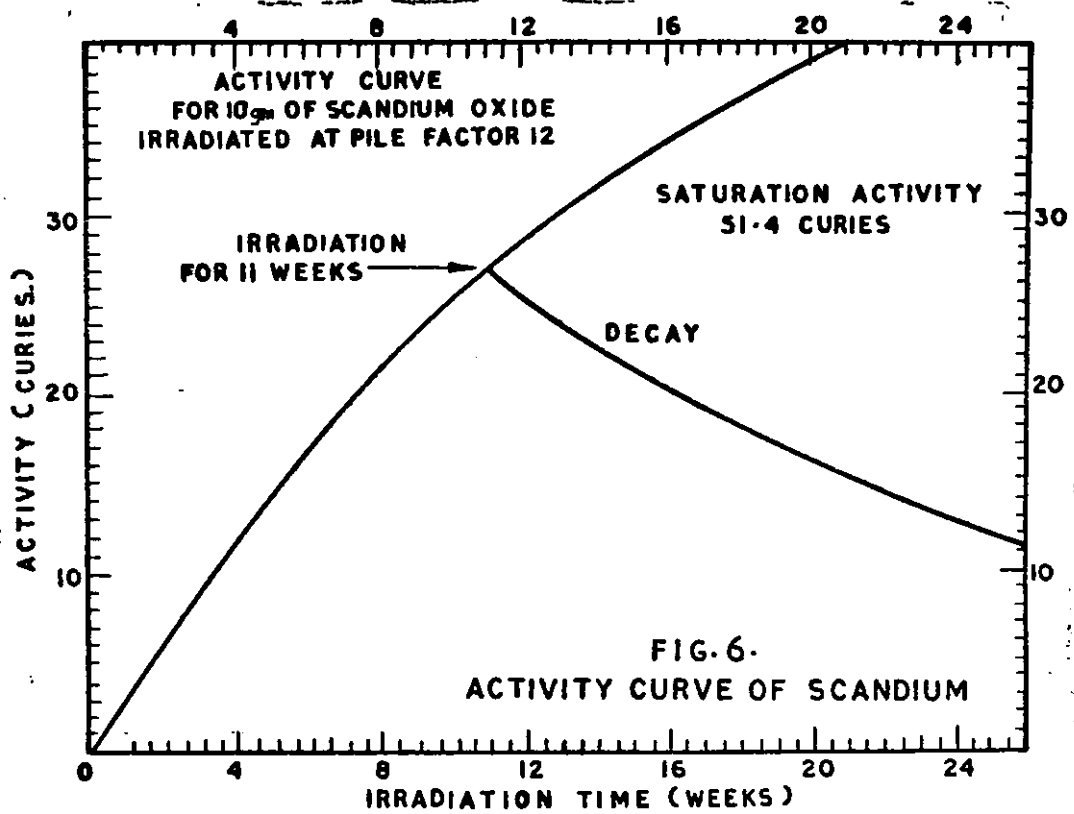


Fig 7 : Corrections to the count rate due to the decay of material

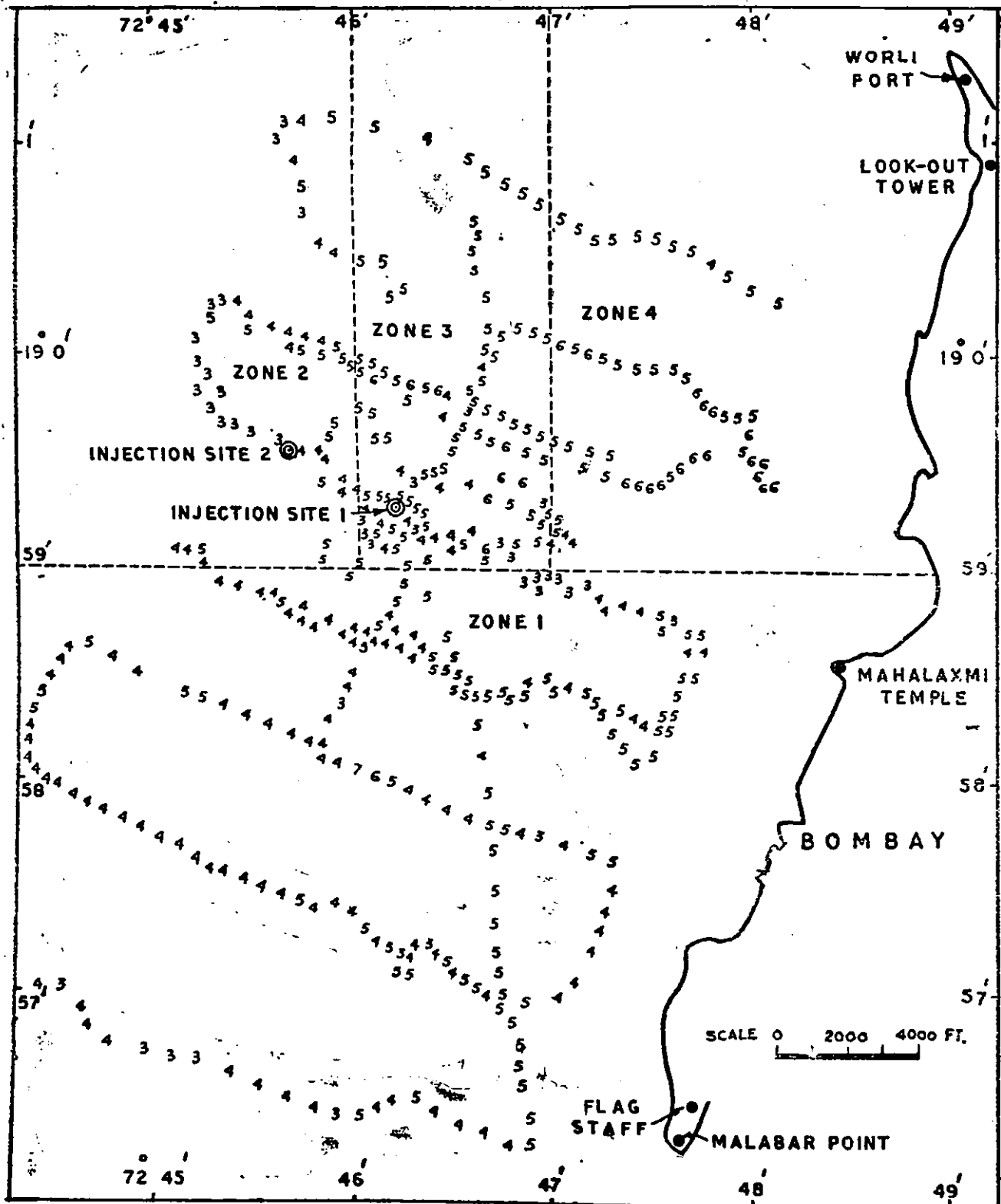


Fig 8 : Background activity in micro - Rontgen / hour

increase the possibility of detection is by increasing the cathode area of the GM counters. This was partially achieved by using 8 GM tubes in parallel.

The equipment was checked aboard the survey vessel before the commencement and at the end of the day's work by using a standardised radium source of 4.5 - 5 microcuries. The radium source was held at 16 positions around the periphery of the brass canister. In the initial stages of the experiment the calibration was of the order of .7 - .8 mR/hr which due to frequent breakages in the hose-pipe during the course of the experiment, dropped to .5 - .6 mR/hr. A possible reason for this drop is the voltage leakage at the terminals and joints in the cable due to the presence of moisture in the hose and in the brass canister. This discrepancy in the calibration necessitated a correction in the count rates obtained.

CORRECTIONS

The corrections can be grouped under 3 categories viz corrections due to variation of day to day calibration, corrections due to decay of the material and the corrections due to the number of counters used in the experiment.

Variation of the operating voltage in presence of moisture affected the observed count rates. In order to standardise this error, laboratory tests were conducted for operating voltage and two other lowered values of voltage obtained by inserting 18.4 m ohms and 10 m ohms resistances respectively which were intended to simulate the drop in voltage due to leakage. These resistances were chosen arbitrarily as accurate values of leakage resistance were not available. Activity readings for a radium source(4.5 - 5 microcuries) held at different positions were

taken for the three voltages. Results of these tests (Table 2, Col 5) show that the count rates vary linearly with the operating voltages.

TABLE 2

Variation in count rates due to a radium source with different leakage resistance in cable

Reading No	Activity in mR/hr			Ratio	
	at operating voltage	with 18.4 m ohms resistance	with 10 m ohms resistance	Col (3) Col (2)	Col (4) Col (2)
1	.920	.800	-	.870	-
2	.730	.640	-	.877	-
3	.650	.550	-	.845	-
4	.560	.490	-	.877	-
5	.410	.350	-	.855	-
6	.220	.190	-	.862	-
7	.125	.105	-	.855	-
8	.073	.063	-	.862	-
9	.045	.037	-	.833	-
10	.028	.024	-	.858	-
11	.020	.017	-	.845	-
12	.940		.520		.553
13	.760		.420		.553
14	.400		.220		.550
15	.175		.095		.544
16	.105		.057		.544
17	.046		.025		.544
18	.016		.009		.544

Thus for applying a correction factor to the observed count rates, .75 mR/hr was considered as a standard calibration and count rates observed on a day of lower calibration than this were boosted up linearly by the corresponding ratio of calibrations.

CORRECTION FOR DECAY

The radioactive isotope continues to decay after its injection on the sea bed. In order to compare, therefore, the count rates obtained every day, it is necessary to apply decay corrections to the day

to day counts. Activity decay is given by the formula

$$A_t = A_0 e^{-\lambda t}$$

where A_t = activity in curies after t days

A_0 = activity at commencement, and

λ = .693/half life of active material

= 1/121.21 for Sc46

$$\therefore A_t = A_0 e^{-\frac{t}{121.21}}$$

ie (count rate after t days over the background rate) $e^{-\frac{t}{121.21}}$
 = (count rate at start over the background rate).

The values of constant for various days are given in Table 3.

TABLE 3

Multiplying constants for correction to count rate on consideration of decay of material(fig 7)

day after 2nd inje- ction (t)	Value of : constant : A_t/A_0	day after 2nd inje- ction (t)	value of : constant : A_t/A_0	day after 2nd inje- ction (t)	value of : A_t/A_0
2	1.02	21	1.19	41	1.40
3	1.02	22	1.20	42	1.41
4	1.03	23	1.21	43	1.42
5	1.04	24	1.22	44	1.43
6	1.05	25	1.23	45	1.45
7	1.06	26	1.24	46	1.46
8	1.07	27	1.25	47	1.47
9	1.08	28	1.26	48	1.48
10	1.09	29	1.27	49	1.49
11	1.09	30	1.28	50	1.51
12	1.10	31	1.29		
13	1.11	32	1.30		
14	1.12	33	1.31		
15	1.13	34	1.32		
16	1.14	35	1.33		
17	1.15	36	1.34		
18	1.16	37	1.35		
19	1.17	38	1.37		
20	1.18	39	1.38		
		40	1.39		

For applying the correction for decay the background activity averaged over four regions(fig 8) was subtracted from the observed activity.

CORRECTION FOR NUMBER OF COUNTERS

It has been mentioned earlier that 8 GM tubes(G24H type) were used for the experiment while the ratemeter has been calibrated for three tubes of the same type. In order to bring the readings to the scale values of dose rates, therefore, they have to be multiplied by $3/8$. Figures 8 to 19 thus give the $Sc46$ activity duly corrected in micro-rontgen/hr above the background activity.

TRACKING OPERATIONS

The sledge carrying the detector unit was dragged on the sea bed by a manila tow rope of 4.55(1 3/4 inch)diameter. The hose carrying electric cable in it was hung loose on the manila tow rope by parachute clips fixed at 4.5 m(15 ft) intervals. The distance between clips was 2.12 m(7 ft) at the end near the sledge in order to prevent the hose from encircling the rock edges.

The vessel used for the survey was motor tug "Anik", 18 m(60 ft) long, requiring 1.8 m(6 ft) draught. During the later stages of the experiment a sistership "Karanja" was used. Enough space was available aboard the tug for manoeuvring the sledge manually in the absence of an automatic winch. The tug towed the sledge at a constant speed of 2 knots.

The positions of the survey vessel were fixed at intervals of 2 min by observing simultaneously angles for three objects on land, namely the Worli look-out tower, Mahalaxmi Temple and the Flag staff at Malabar Point. The angles were taken by sextants and were plotted on site.

In the initial stages of the experiment permanent records of activity were kept by a recorder. But during the later stages, in absence of such a machine, ratemeter readings were observed at every 15 sec intervals.

BACKGROUND ACTIVITY(Fig 8)

During latter part of February and early March an extensive survey of background radio-activity was made in the vicinity of the injection site by running survey lines at 0.8 km(1/2 mile) intervals. The area covered was upto 4.01 km(2½ miles) to the north of the injection site, ie upto Worli and 4.82 km(3 miles) to the south upto Malabar Point while the west to east limit was 4.1 km(2½ miles). Background activity to the south of the injection point was fairly uniform and had a value of 4 mR/hr. In the area to the north of the injection point the activity increased towards the coast. Towards the NNW of injection site, the activity was of the order of 4 mR/hr, and it increased towards the coast upto 6 mR/hr.

On some days of background survey the sea became rough and it was thought that there should be an alternative site for injection inside the harbour serving for a pilot study during bad weather. Hence a site on the Karanja spoil ground discarded in 1932 was chosen as an alternative. Background activity was about 4 mR/hr in this area.

Background activity was also measured at the entrance to the harbour. These observations were essential in order to detect the movement, if any, of the tracer in this area. The observations indicated an activity of 3-4 mR/hr.

INJECTION APPARATUS

It was decided to mix the radioactive tracer with the natural

sediment in the injection apparatus before injection for reducing the chances of its going into suspension and to make it behave in the same way as natural silt. The injection apparatus used was similar to the one used in the Thames Estuary Experiment with some modifications. The container had two flap doors mounted by means of springs and a trigger for releasing the springs to open the doors (Photo 6). The trigger was operated remotely by a compressed air actuator which consisted of a piston having a run of 5.1 cm (2 in). This movement of piston was sufficient to push the trigger into operation. The injector was also covered from 4 sides by an aluminium skirt 0.9 m x 0.9 m (3 ft x 3 ft) which was essential to stop the injected fine material from dispersing. Another precaution taken to prevent suspension of material was to lock the injector in a vertical position and keep only the bottom door operable.

LABORATORY HANDLING

The radioactive tracer arrived in Bombay in two shielded containers 865 kgm (17 cwt) each which were taken to the Radio-chemical Laboratory, AEE, at Trombay. The cans were opened remotely by tongs behind a 10.2 cm (4 in) lead wall in a fume cupboard when the tracer was found in a solidified state and not as powder. It was, however, possible to extract the glass from the container by spiking the surface of the solidified powder and removing the loosened material layer by layer. Obviously, the size distribution of the glass was much coarser than it was before irradiation. The glass was shaken in a container with steel balls for 30 min. Settling tests in a column of sea water on small samples of tracer thus obtained, indicated a size gradation similar to the required. Hence it was decided to proceed with the first injection of 400 gm of tracer.

FIRST INJECTION

The first injection was done on HW slack of 14th March 1959 at 15.00 hrs at a position 4.01 km ($2\frac{1}{2}$ miles) offshore of Mahalaxmi Temple (fig 1) in order to give a bias towards south by the following ebb tide. The range of ebb tide was 2.5 m (8.3 ft) and the sea was very calm. To start with, the injector was half filled with mud containing 300 percent moisture which corresponds to the natural moisture content of the silt. One-inch layer of fresh water with a wetting agent was added to encourage its mixing with silt by reducing surface tension. The aluminium can containing 400 gm (curies) of tracer shielded by a 865 kgm (17 cwt) lead pot fixed on ship was raised by pulling wires until enough portion of it appeared above the pot. It was then gripped by a .9 m (3 ft) handling tong and transferred to its position on the spike inside the injector so that the glass lid rested on the spike. In closing the injector the aluminium can got pressed and opened by breaking the glass lid. The injector was then vigorously shaken for one minute by turning it through 360° by a 2.41 m (8 ft) handle (Photo 7). The apparatus was then lowered on the sea bed and was opened remotely by compressed air. The appearance of rubber balls which were put in the injector prior to the mixing of active material indicated successful opening. The injector was left on the sea bed for one hour to allow the injected material to settle within the skirt. On bringing the injector to the surface it was found that though the glass lid was broken some powder had clogged inside the can. The can was pulled free with an eight ft handling tong and was thrown into the sea for fear of contamination. The percentage of tracer actually injected thus remained unknown as also the state of the material clogged inside the can. Thus

the injection was not quite satisfactory. It was decided, therefore, to devise a better method for using the remaining tracer material.

SECOND INJECTION

For the second injection the tracer from the second can was put into slurry so as to prevent its conglomeration. About 325 grams(7 curies) of the tracer was kept in suspension in 450 cc of pure water. The contents were stirred with a magnetic stirrer. During stirring the slurry was transferred into a container 6.35 cm($2\frac{1}{2}$ in) diameter and 32.5 cm (12 in) long with a glass base.

The position for the second injection was selected in such a way as to have minimum interference with any moving tracer from the first injection. A site .9km(3000 ft)westwards was accordingly chosen. The injection of slurry was done on 19th March at High water slack(Tbb range = 1.3 m(4.3 ft)). The handling of tracer and mixing it with natural silt was similar to the first injection but the glass base of the container was smashed on the spike inside the injector and the container raised so that the draining out of the slurry could be visible. Other procedure being similar the injector was lowered to rest on the sea bed, opened remotely and left on the bed for $1\frac{1}{2}$ hours to allow settlement. On raising the injector, traces of mud were seen on one side and the lifting frame had bent. This indicated a possible heeling of the injector on its side which might have disturbed the silt and the tracer in the vicinity.

PROTECTION

Handling large quantities of active material in restricted space demands considerable experience on the part of experimenters. In the present experiment activity was handled in batches of 7-8 curies in a

4.8 m x 4.8 m (16 ft x 16 ft) space available on the vessel. This space was screened on three sides in order to shield it against winds (Photo 8). Skilled personnel from the Atomic Energy Establishment who were specially trained for the job, manoeuvred the handling of active material, its mixing with natural silt and its injection on sea bed. Handling the active material by 0.9 m (3 ft) tongs was found convenient and sufficiently safe. The maximum radiation dose received by the personnel was 20 mR as compared to the tolerance dose of 150 mR.

Apart from protection to the personnel conducting the experiment it was necessary to estimate the hazards to the general public by such experiments. In the present experiment there was no possibility of danger from direct radiation as the depth of water acting as a shield in the study area was more than 9 m (30 ft). However, as some fishing is done in the area it was necessary to estimate the probable dose communicated through this agency.

The radioactive scandium glass used for the experiment can be assumed to be consisting of 5×10^{11} mean-sized particles, having an average activity of 30×10^{-12} curies each. These particles were expected to be dispersed and mixed with silt on site. Now, the maximum permissible quantity of scandium 46 which may be absorbed in the human body is 6×10^{-6} curies. Thus, it can be seen that a human being will have to consume a considerable quantity of fish contaminated with active silt before any danger can arise. Hence no special precautions were thought necessary for protection to the general public.

TRACKING HISTORY

The plots (figs 9-19) show activities of injected material in mR/hr after eliminating the background activity. The dose rate of 3 mR/hr

which is equal to 75 percent of the background activity is assumed to be a significant activity and that of 35 mR/hr indicates the ~~total~~ zone of concentrated activity which serves as a feeder zone. The total run of tracking done for this experiment was about 564 km(350 miles).

DAY OF 2ND INJECTION(Fig 9)

The injected material was tracked 2 hours after the injection. A long streak of activity was noticed in the direction of ebb currents, extending upto 1500 m(5000 ft)to the south of injection site. As mentioned earlier, the injector while being pulled up, might have disturbed the silt in the vicinity to be carried away by the ebb current. The phenomenon cannot be attributed to the bed movement. A patch of activity to the east of the main spread may be due to the 1st injection.

2nd DAY AFTER INJECTION(Fig 10)

The sea continued to be calm with neap tides. The activity was seen to have dispersed towards the west and the width of the significant activity increased from 240 m(800 ft)average on the day of injection to 330 m(1100 ft)average having a maximum width of 630 m(2100 ft). Two patches of activity were detected to the north of injection buoy. The tracer in general had dispersed towards west. The tracer dumped on site 1 was also tracked to see whether it had mixed with the tracer on the 2nd site. No such tendency was found.

3rd DAY AFTER INJECTION(Fig 11)

Tracking on 3rd day after injection showed a major spread of activity towards the north, the spread in other directions being as before. The tip of northern spread was 570 m(1900 ft)from the injection site as compared to 240 m(800 ft)observed on the 2nd day's tracking.

5th DAY AFTER INJECTION(Fig 12)

The sea remained fairly calm and the dominant tide of 3-3.3 m

72° 46'

19° 0'

19-3-1959

TIDES:-

TIME (HRS.) HEIGHT (FT.) RANGE (FT.)

01-15	7-8	1-8
06-06	9-6	4-3
13-02	5-3	5-9
20-22	12-2	

WAVES:-

SEA WAS CALM THROUGHOUT THE DAY.

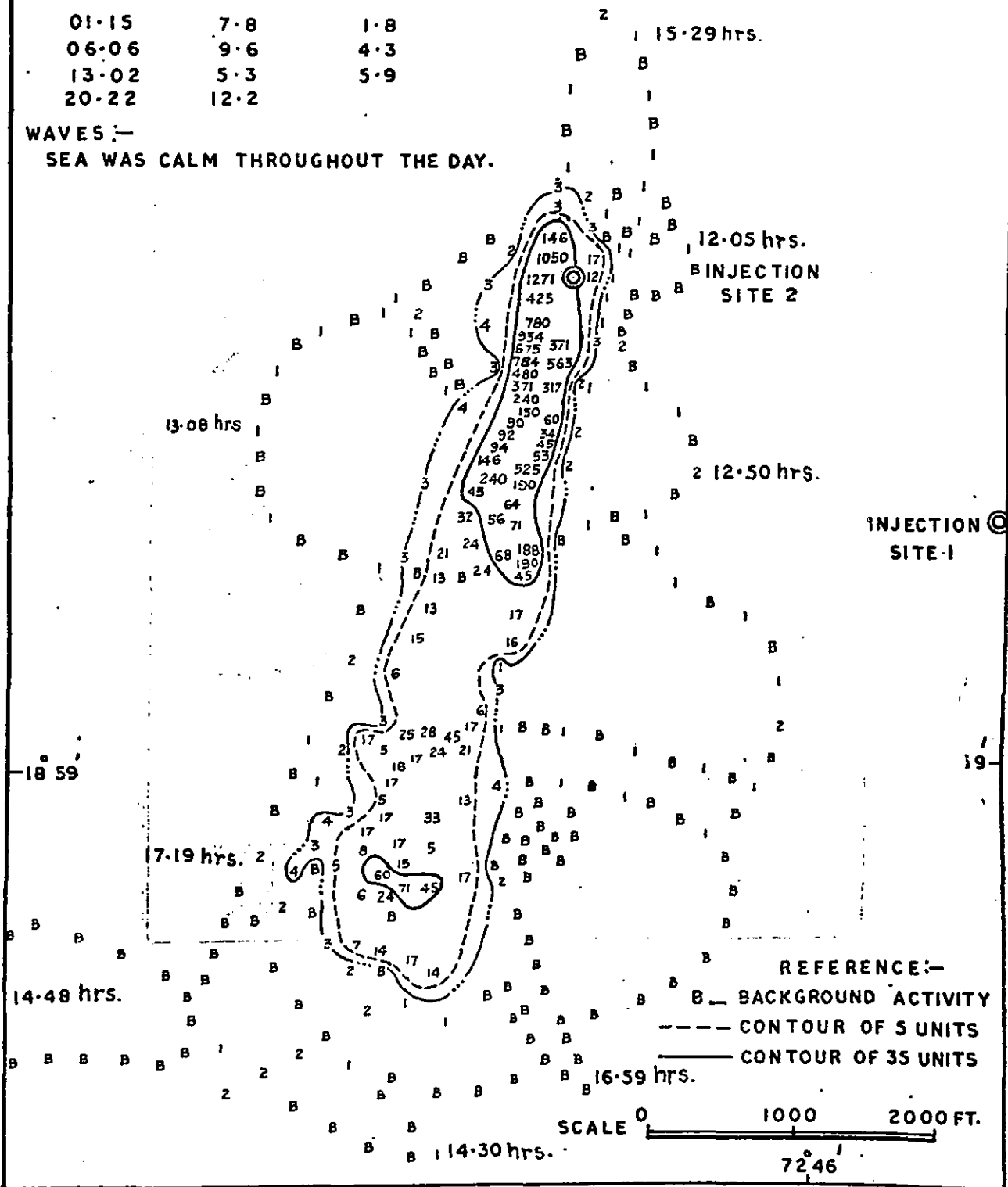


Fig 9 : Activity in micro - Rontgen /hour over the background activity on the day of 2nd injection

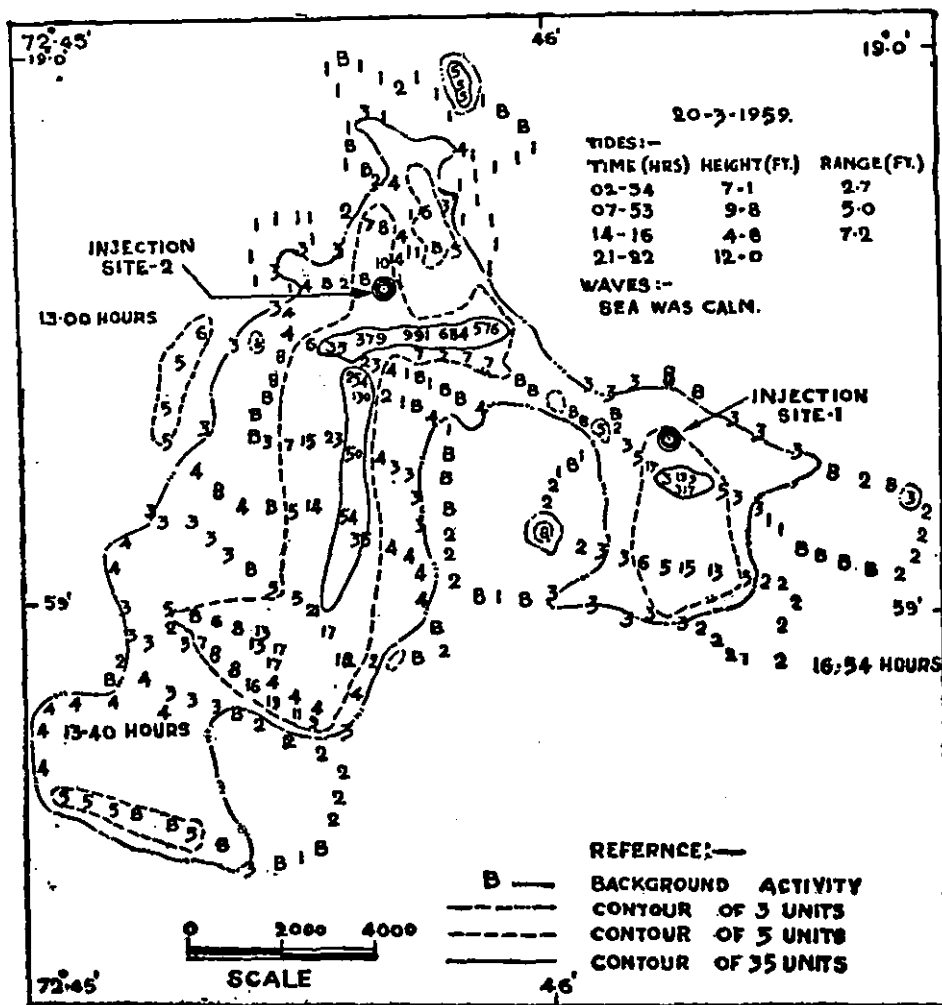


Fig 10 : Activity in micro - Rontgen /hour over the background activity on 2nd day after 2nd injection

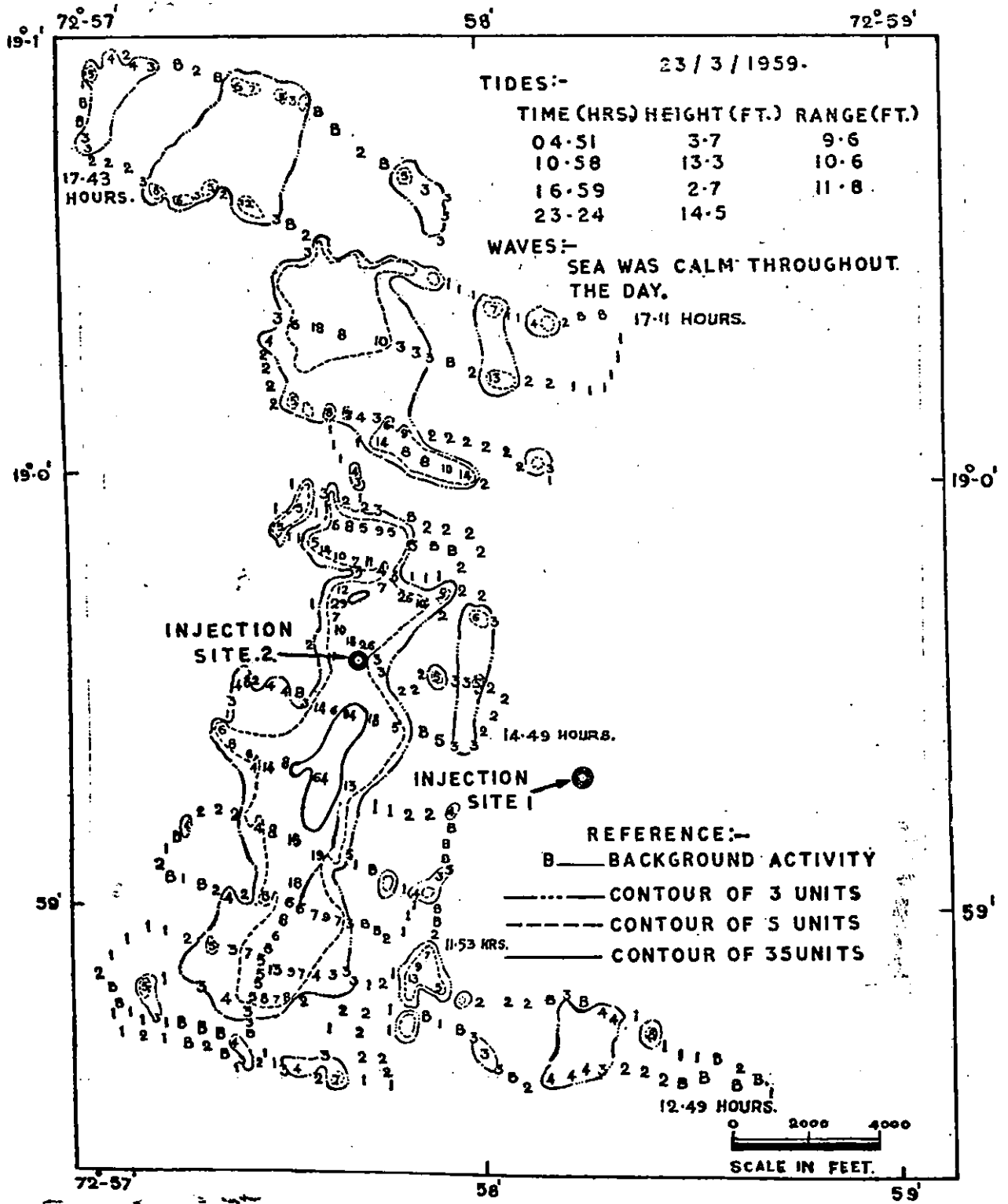


Fig 12 : Activity in micro-Rontgen/hour over the background activity on 5th day after 2nd injection

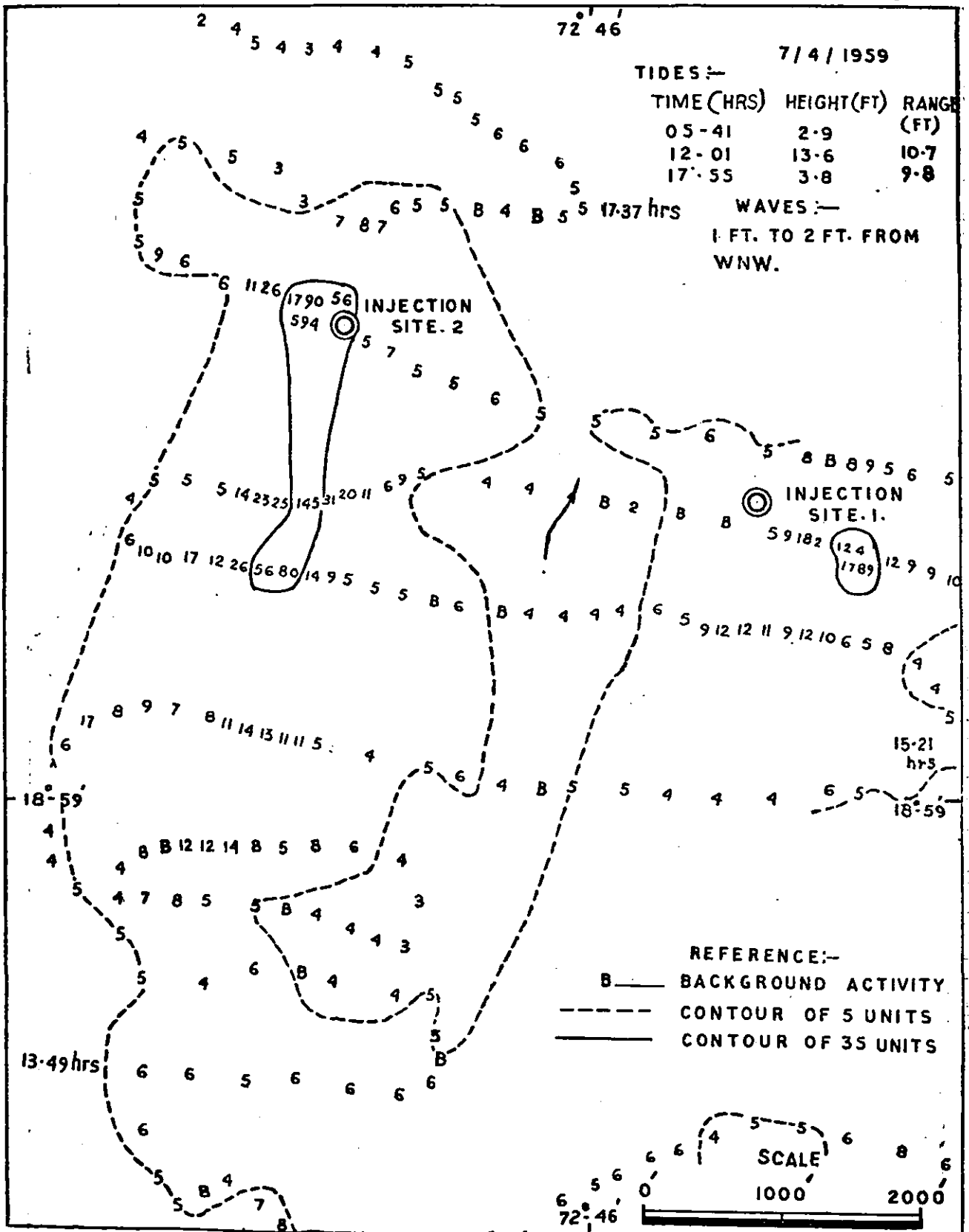


Fig 14 : Activity in micro-Rontgen/hour over the background activity on 20th day after 2nd injection

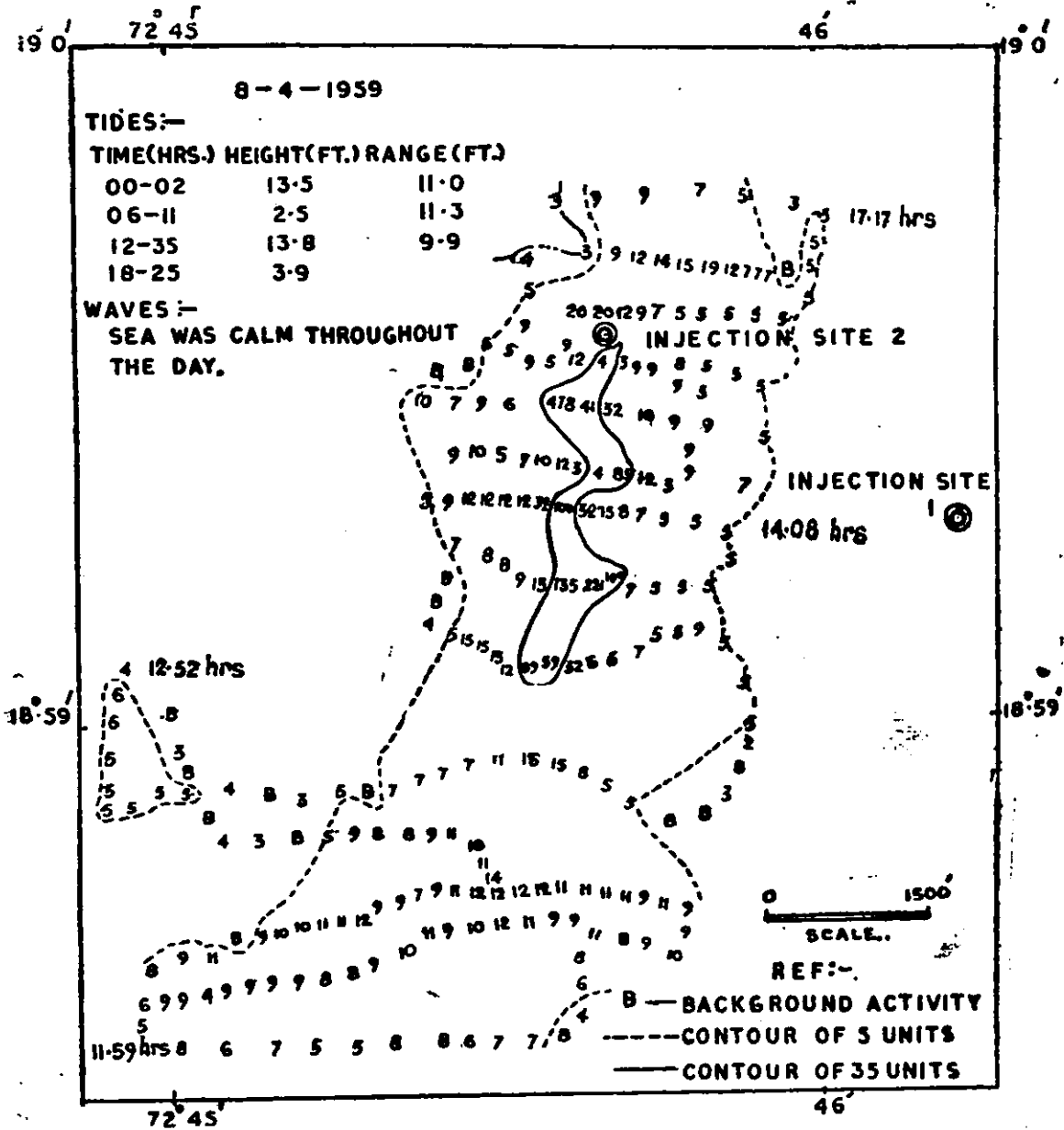


Fig 15 : Activity in micro-Rontgen/hour over the background activity on 21st day after 2nd injection

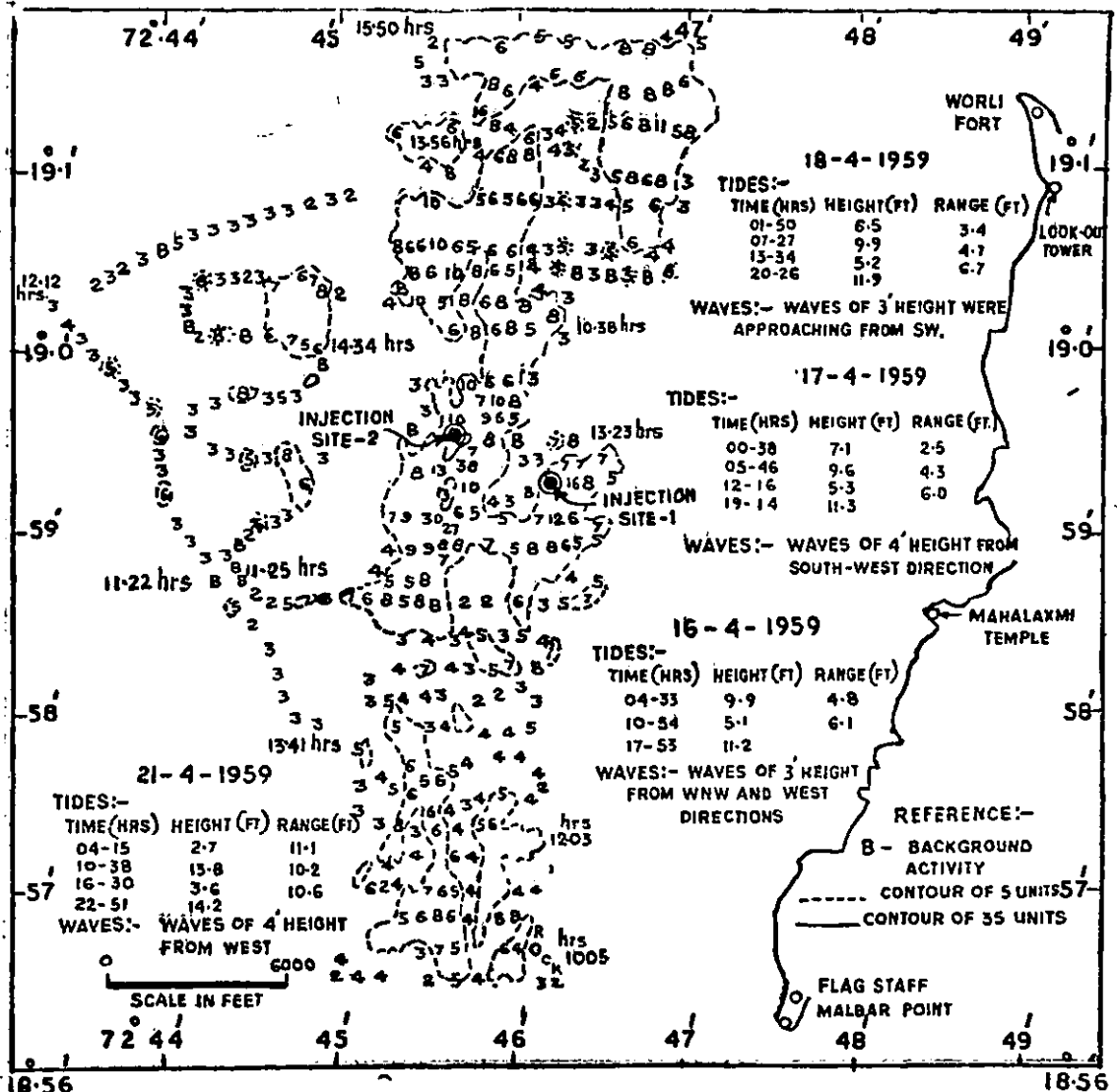


Fig 17 : Activity in micro-Röntgen/hour over the background activity on 29th, 30th, 31st and 34th day after 2nd injection

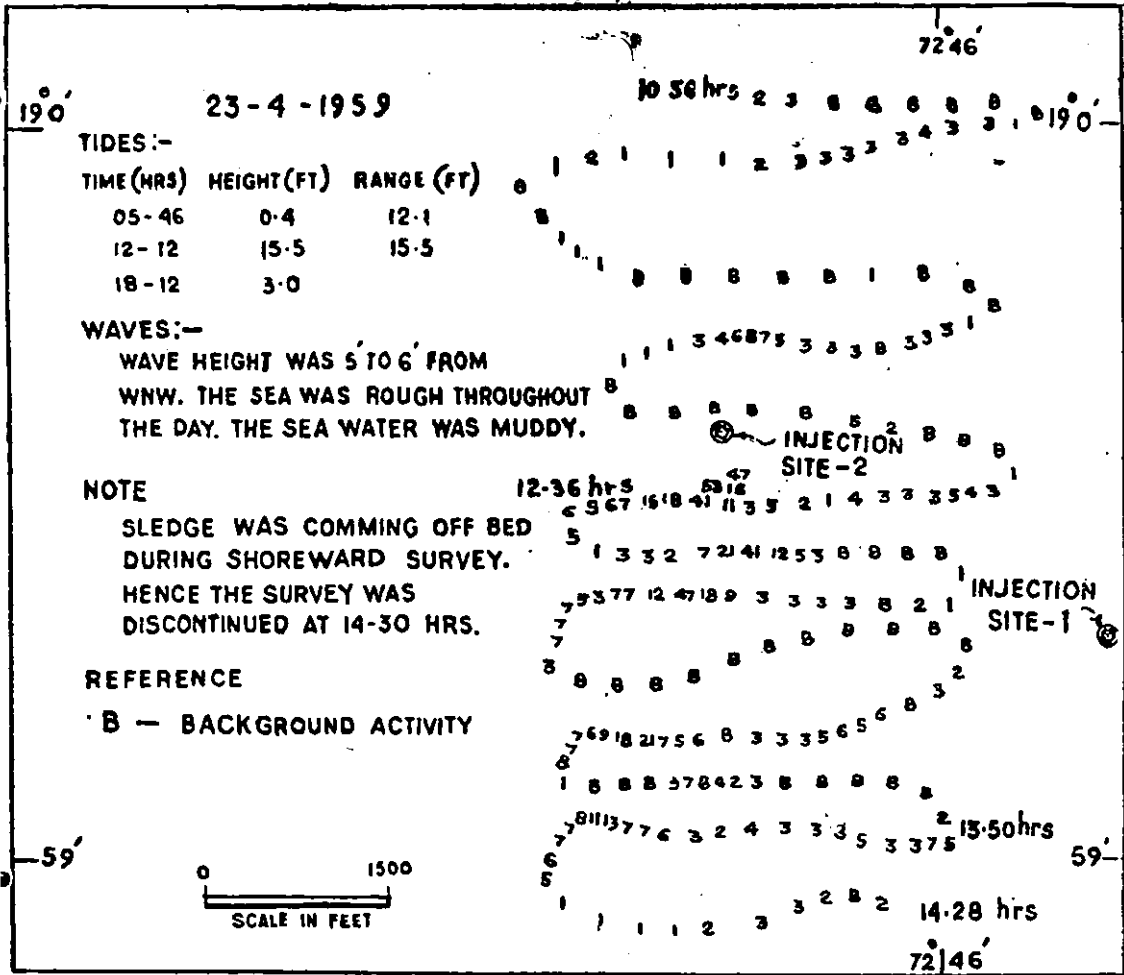


Fig 18 Activity in micro-Rontgen/hour over the background activity on 36th day after 2nd injection

(10-11 ft) range had commenced. The tracking revealed two big patches of significant activity towards north of injection site at distances 840 m (2800 ft) and 1290 m (4300 ft) respectively. This clearly indicated the movement of tracer towards north through the agency of tidal currents. The sea had been calm since the day of injection and hence only the tidal currents had been causing the bed movement. A patch of activity observed to the SE of main spread might be due to the 1st tracer.

16th, 17th and 18th DAY AFTER INJECTION (Fig 13)

The tracking done on these days was not satisfactory due to frequent breakage of the hose pipe. The breakages prevented the coverage of the entire area. Though a patch of activity was located towards the north of the main spread, no comparison was possible as the southern portion could not be surveyed.

21st DAY AFTER INJECTION (Fig 14)

A long time had elapsed since the previous tracking. The sea had been very rough on account of spring tides. Some failures occurred in the tracking equipment which prevented tracking.

Tracking on 21st day showed the activity dispersed as on the 2nd day. The patches of activity which were found on 5th day had vanished. The concentration of activity had also reduced considerably. The interim period of rough sea and high tides must have dispersed the material at greater distances.

22nd DAY AFTER INJECTION (Fig 15)

The southern tip of spread had broadened, the increase in width being more towards the west. An isolated patch of activity was located to the west of the main spread.

The day was very calm and dominant tides were running. The tracking of this day and previous trackings on calm days clearly indicated

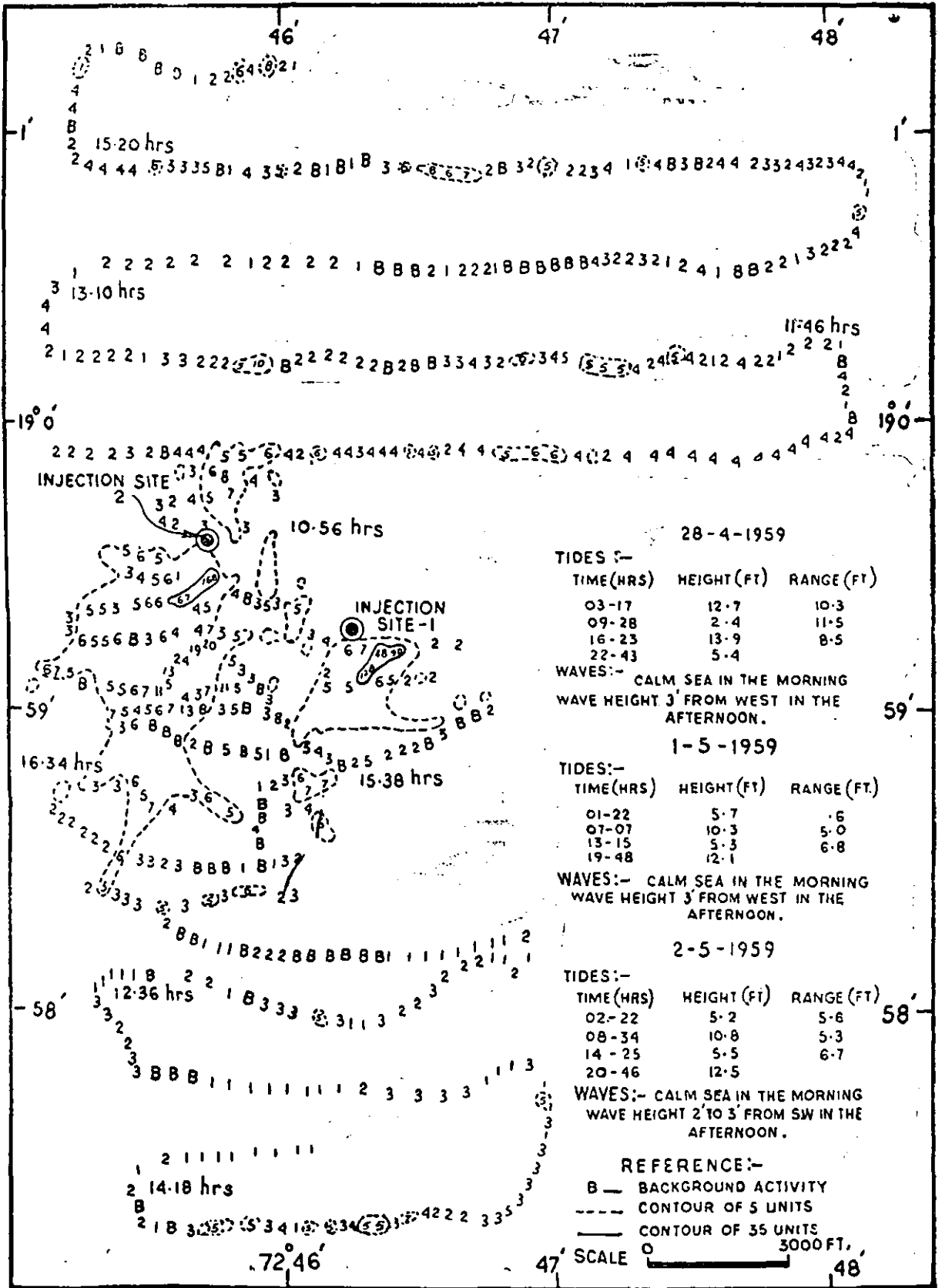


Fig 19 : Activity in micro-Rontgen/hour over the background activity on 41st, 44th, 45th day after 2nd injection

that the tidal currents had a tendency to move the tracer towards west and north. The continuous belt of activity was still near its initial position.

25th DAY AFTER INJECTION(Fig 16)

The sea was rough with spring tides. Tracking revealed that the spread of activity had bodily shifted towards the east by about 500 ft. No other significant change was noticed.

30th, 31st, 32nd and 35th DAY AFTER INJECTION(Fig 17)

It was mentioned earlier that due to rough weather from 28th March to 2nd April, much of the activity had dispersed. The object of this 4 days' survey was to cover the area from Worli Fort to Malabar point with a hope to locate the dispersed tracer.

The tracking on these 4 days showed patches of significant activity towards north and NNE of injection site as far as 3.22 km(2 miles)away, and some stray patches were also found towards the south but they were insignificant in area compared to the patches in the north. In order to find details of dispersion, activity lower than the significant activity was also studied. For this, a contour of 3 mR/hr was plotted. The dispersion of this value 3 can be seen to be more towards the north than towards the south. The continuous belt of activity, however, remained near its initial position.

37th DAY AFTER INJECTION(Fig 18)

Spring tide was running with very rough sea. The object of survey was to locate the limits of concentrated activity spread. This could not be done satisfactorily due to the rough weather.

42nd, 45th, and 46th DAY AFTER INJECTION(Fig 19)

The tracking included areas to the north and south of the main spread of activity for ascertaining the details of the main spread. Isolated patches of activity were observed towards north and west of

the main spread. Stray patches of smaller areas were also located towards the south. In general, the dispersion of tracer was more towards the north.

The sea had already started becoming rough and though mornings were relatively very calm, in the afternoons, the sea became much too rough to carry out any further tracking. This reduced the working time during a day. Thus on account of limited working hours per day, covering the entire area would have required more days. It was impossible otherwise also to continue the survey on the onset of SW waves. Tracking was, therefore, discontinued till the end of monsoon season.

Tracking was recommenced $7\frac{1}{2}$ months after the injection when the sea conditions improved. However, due to the decay and dispersion, the intensity of active tracer in the study area was so feeble that only the back-ground activity was perceptible.

CONCLUSIONS

Examination of the charts of day-to-day tracking clearly shows that though the main spread of significant activity simply oscillated about its initial position, the dispersion of tracer had been more towards the north than in any other direction. As the waves had been from NW and W throughout the experiment this northerly dispersion of activity was against the wave action and was hence chiefly due to the tidal currents. Moreover, the waves from NW and W had a smaller duration and intensity as compared to those from SW. These SW waves will further help in the northerly transport of the material dumped at the injection site due to the long-shore current caused by them. Thus there is very little chance of the dumped material travelling towards the entrance of the harbour. The site can, therefore, be considered a safe dumping ground for the material dredged from the channel.

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- **S. V. Bhawe, I. A. S., Municipal Commissioner, Poona Municipal Corporation, at the Poona Municipal Press, Ghole Road, Poona 5.**
- **M. G. Hiranandani, Director, Central Water and Power Research Station, Poona 3.**