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ASSESSMENT OF SILTATION RATE AND SEDIMENT TRANSPORT IN BOMBAY HARBOUR BASED ON CESIUM-137 DISTRIBUTION*

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ABSTRACT

Low level aqueous radioactive wastes from the nuclear complex at Trombay are discharged into the Bombay harboui. Of the six principal radionuclides comprising the discharge, cesium-137 is most predominantly taken up by silt from the sea water.

Isoactivity contours show that activity levels just off the point of discahrge, and further south to Pir Pau, were between 50 and 100 pCi/g. Activity in the main channel of the harbour remained below 10 pCi/g, while further north (beolw the Thane Creek bridge) it was around 20 pCi/g.

Activity in the top six centimetres of a core off Trombay naval jetty was less than 5 pCi/g, reaching a maximum of 178 pCi/g at 14 cm below the surface. Thereafter, it tapered off to 5 pCi/g down to a metre.

INTRODUCTION

Low level aqueous radioactive wastes from the nuclear complex at Trombay are discharged into the Bombay harbour. These comprise principally of cesium-134 and -137, cerium-144, ruthenium-106, zirconium/niobium-95, strontium-90, and uranium and its daughter products. Of these, cesium-137 is found to be most predominantly taken up by silt from the sea water (Pillai *et al.*, 1975), being distributed in sediment throughout the harbour, while cerium and ruthenium in sediment have been limited to areas immediately off the point of discharge. Mulay (1972) has carried out an extensive radioecological survey of the Bombay harbour from 1968 to 1971. His studies have shown a horizontal spread of activity during this period as well as a vertical build-up of radionuclides in the bottom sediment. The present investigations were carried out by us in 1973-74 to assess further changes; the data collected from this follow-up study has not only confirmed that the level of activity due to 137_{Cs} is changing, but an interesting pattern

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of vertical distribution of activity is revealed which can be put to use to determine the rate of siltation in the harbour.

MATERIAL AND METHODS

37 stations in the Bombay harbour (Fig. 1) were selected for the present study. Surface sediment samples were collected by means of a Berge-Eckman dredge, while 1-metre cores were obtained with the help of a Phleger corer. The cores were cut into 5-cm segments, except the top 10 cm, which were cut into four (2.5 cm) sections. The sediment, after removal of any coarse matter such as shell pieces, animal remains, etc., was dried at 105°C and homogenized. 15-20 gm samples were tightly packed in plastic vials (8 x 2.5 cm) and the gamma

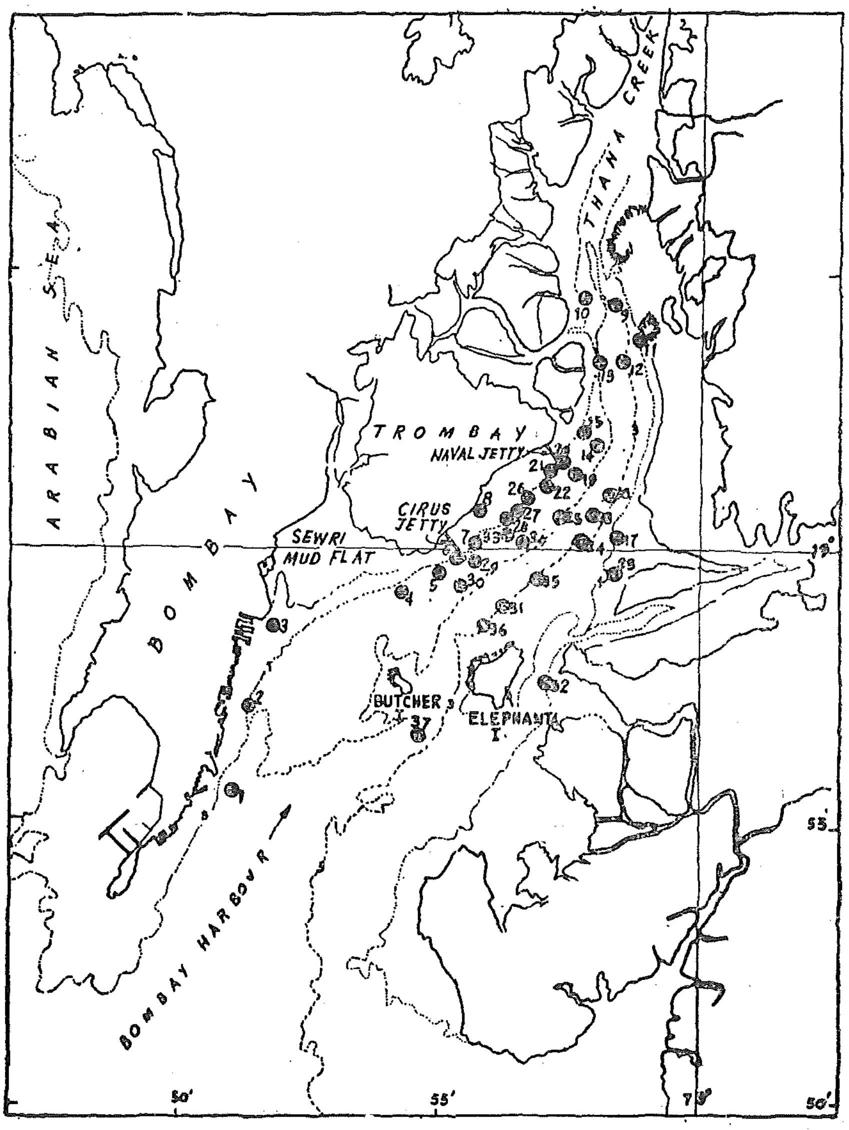

Fig. 1. Map showing location of stations.

activity counted in a well-type NaI (Tl) scintillation crystal coupled to a 512 channel pulse height analyzer. The total counts in the 0.66 MeV photopeak energies, corrected for background, were converted to activity in picocuries (pCi) per gram, by comparing with earlier harbour sediment samples of known activity values, which had been calibrated by the IAEA, Vienna, and which were counted in the same geometry (*i.e.* 15-20 g in 8 x 2.5 cm plastic vials).

RESULTS

The distribution patterns of Dec. 1973-Jan. 1974 ^{137}Cs activity, shown as isoactivity contours, are shown in Fig. 2. The activity levels just off the point of discharge (between Trombay naval jetty and the plutonium plant), and

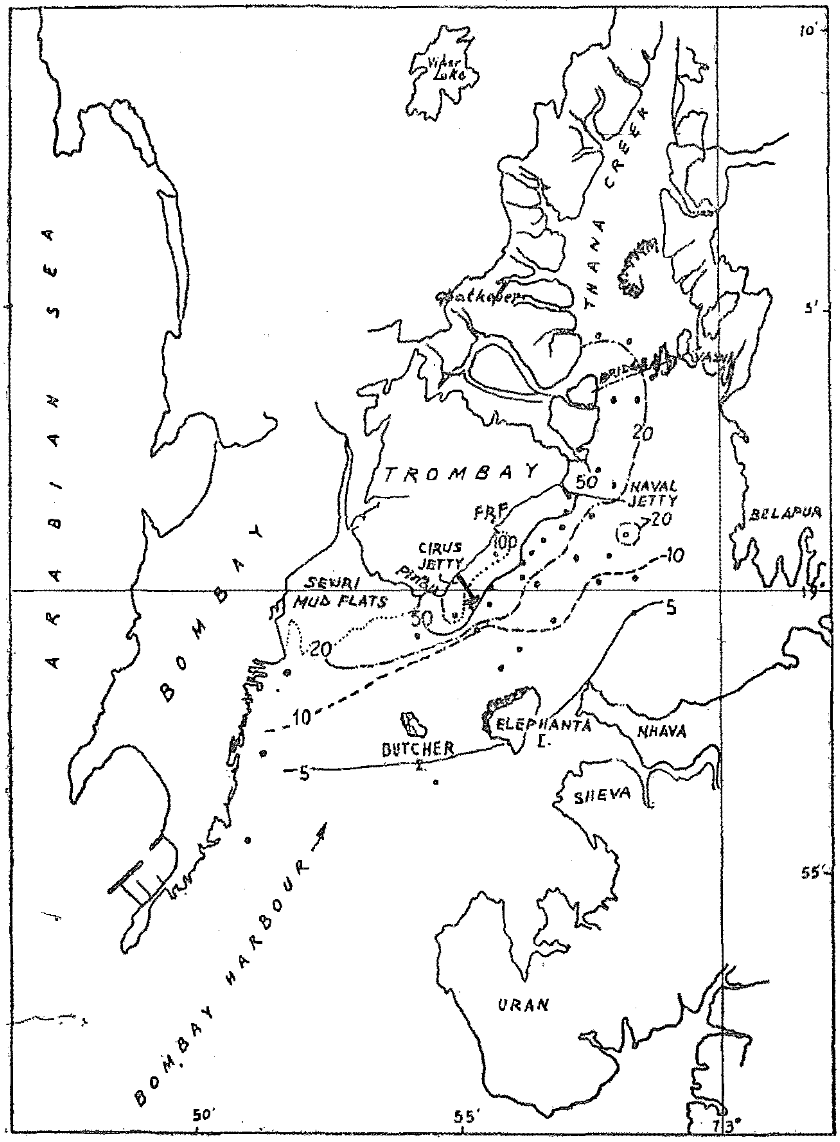

Fig. 2. Distribution of radioactivity in bottom sediments of Bombay harbour in 1973-74.

further south. from the Cirus jetty-Pir Pau area, were between 50 and 100 pCi/g. reaching in some cases to even 150 pCi/g (*e.g.* at Station 8). Activity in the main channel of the harbour, *i.e.* between Elephanta Island and Butcher Island, as well as around the former island, remained below 10 pCi/g. The activity levels in the channel further north, *i.e.* at the middle of the Thane creek bridge to Vashi, also remained constant around 20 pCi/g. An isolated pocket with activity levels over 20 pCi/g. An isolated pocket with activity levels over 20 pCi/g. at Station 16, west of Belapur, may be noted.

Of the core samples taken. three, *viz.* near, north of, and south of the discharge point, are considered here. Fig. 3 shows the levels of activity at and below the surface in sediment from these three stations. For station 22, just south of the

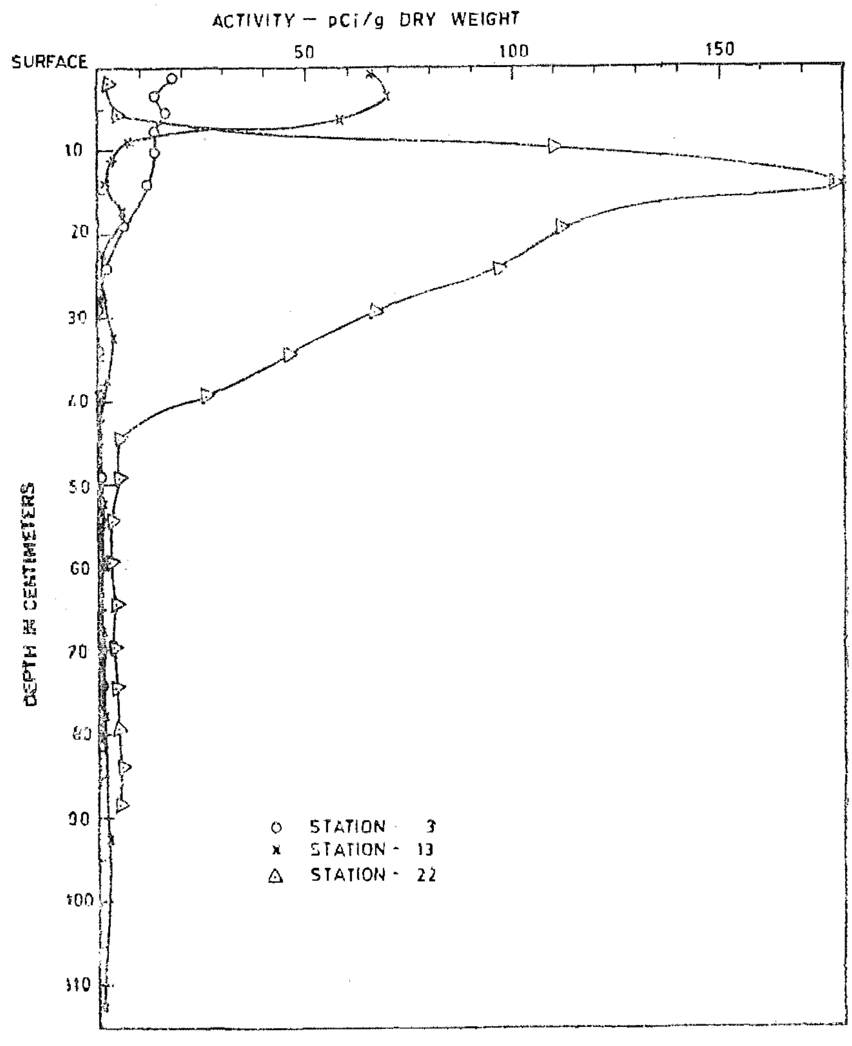

Fig. 3. Distribution of radioactivity in harbour sediment below water-sediment interface.
Station 3 — Off Hay Bunder. south of Sewri mudflats;
Station 13 — at western end of Thane Creek bridge;
Station 22 — south of Trombay naval jetty.

Trombay naval jetty, down to about 6 cm below the surface, the activity level is less than 5 pCi/g, but, thereafter. it shows a sudden increase, reaching a maximum of 178 pCi/g 14 cm below the surface. Thereafter the activity level tapers off, being only 5 pCi/g 45 cm below the surface. Below this depth, down to almost a metre, the level of activity is constant, at 5 pCi/g.

Activity levels in a core from the western end of the Thane Creek bridge (station 13) are also shown in the figure. Activity at the surface, being 66 pCi/g, increases only marginally, to a maximum of 71 pCi/g, at 4 cm below the surface. It then tapers very steeply to 8 pCi/g 8 cm below the surface. At 22 cm and below, the activity level remains fairly constant, around 2 pCi/g.

At Station 3, immediately south of the Sewri mud flats and just off Hay Bunder, the activity level in tre first five centimetres is about 18 pCi/g. It then tapers off gradually to 3 pCi/g at 25 cm below. Thereafter the activity is almost nil down to a metre (and below).

DISCUSSION

Discharge of waste with fair levels of activity into the harbour may be said to have started from 1964, when the irradiated fuel reprocessing facility (plutonium plant) with a nominal capacity of 30 tonnes U/year started operation. These discharges reached a peak level in 1971-72; thereafter discharges were at considerably decreased levels. Table 1 gives the quantities of total

Table 1. Discharge of radioactivity into Bombay harbour from fuel reprocessing plant — 1964 to 1974.

YEAR	CURISE—STRONTIUM-90 EQUIVALENT
1964	Data not available
1965	2.0
1966	75.19
1967	64.13
1968	110.29
1969	190.23
1970	304.41
1971	378.06
1972	138.99
1973	59.90
1974	28.69

* V. D. Vashi (Personal communication)

β activities released from the Plutonium plant between 1965-1974. One could, therefore, expect a reduction in the activity levels of surface sediment from 1971-72 to 1973-74.

Comparison of Fig. 2 with Fig, 4 (after Mulay, 1972) shows that a few significant changes have taken place. It may be noted that the high levels (of from 200 to 400 pCi/g) found by Mulay, were from mud collected from the shore, off the BARC campus. Since the 15-metre boat from which the present

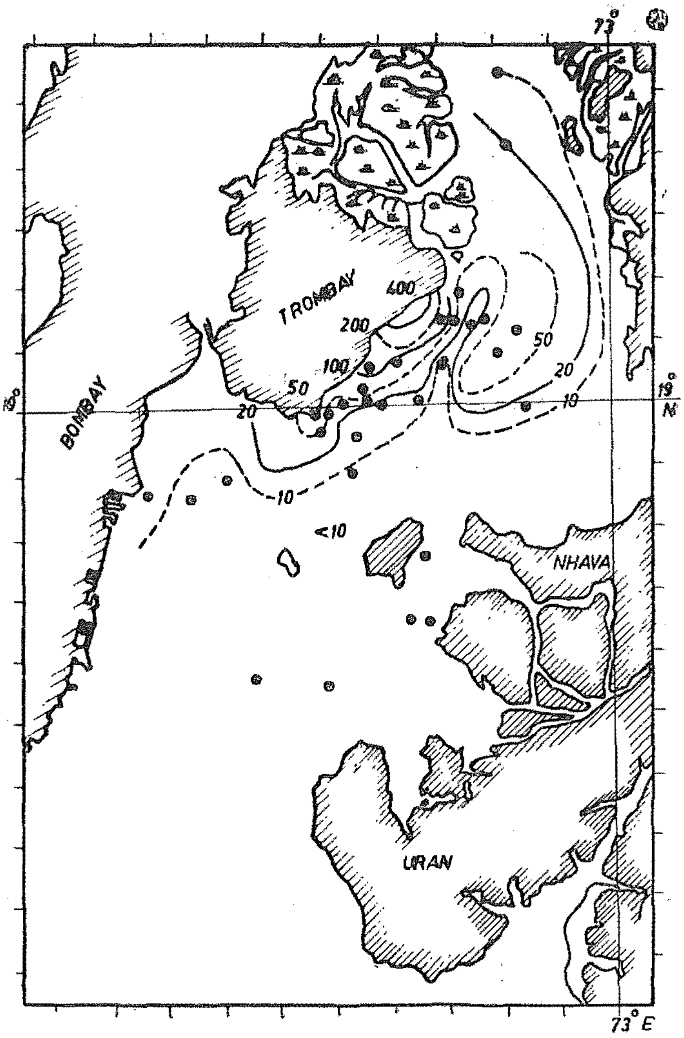

Fig. 4. Distribution of radioactivity in bottom sediments of Bombay harbour in 1971 (After Mulay, 1972).

samples were collected could not approach so close to the shore, the stations were made in a minimum depth of two metres. The 50 pCi/g isoline occupies nearly the same contours in 1973-74 as in 1970-71.

The 20 pCi/g isoline continues to run from Ghatkopar in the north to the southern tip of Trombay. However, there appears to be an extension of this level of activity to the outer reaches of the Sewri mud flats; sediment from this region in 1970-71 had shown levels only up to 10 pCi/g at this place.

The 100 pCi/g isoline has also extended further south up to Pir Pau; in 1970-71 it reached only up to a point north of the Cirus jetty.

The abrupt bending in of the 10, 20 and 50 pCi/g isolines east of Trombay, a feature indicated by Mulay for 1970-71, is absent for 1973-74, the isolines being smooth.

Activity in the southern half of the harbour continues to remain below 10 pCi/g.

From, the above, it can be concluded that there is a gradual "creeping" of activity levels southward from the point of discharge, this being insignificant northward.

The isolated pocket of higher activity (20 pCi/g) at Station 16, is of interest. Mulay has remarked on similar isolated pockets of high activity, especially off Sewri, at Belapur, and under Kalwa bridge at the northernmost tip of Thane Creek, all shallow regions.

The peculiar distributions of these pockets of high ^{137}Cs activity in the shallow regions of Bombay harbour can be explained if one takes a close look at the sorption behaviour of ^{137}Cs on sediments and the pattern of siltation in Bombay harbour. ^{137}Cs is picked up more by the fine fractions of sediments, particularly by the clay mineral illite. The shallow tidal flats bordering the harbour and at the end of Thane Creek are silting up at a fast rate. The pattern of siltation in Bombay harbour is apparently similar to that of the Dutch Wadden Sea. The silting up of the shallows in the Dutch Wadden Sea has been lucidly explained by Vaan Straaten & Kuenen (1957) and by Postma (1961). Their explanation seems to hold good for Bombay harbour as well. Depths, tidal current velocities and suspended matter concentrations in Bombay harbour are comparable to the Dutch Wadden Sea. The flood tide, with a certain current velocity, brings a lot of sediment in suspension, and the suspended silt moves inward along with the water mass. The current velocity decreases as the water mass moves inward. Although, theoretically, the suspended silt should settle as the velocity approaches the initial velocity at which it was suspended, in practice it remains in suspension for some more time, due to a settling lag, and the particle is carried inward and settles in the low lying area. When the tide reverses, the water mass has to travel some distance before it picks up sufficient velocity to bring the particle in suspension. Thus, fine particles, bearing sorbed ^{137}Cs get progressively transported towards the shore. This explains why activity builds up to a higher level in these shallow pockets, even though the activity level in regions surrounding these pockets is low (due to there being no settling of activity-bearing silt particles here).

Hiranandani & Gole (1960) reported siltation rate in Bombay harbour to be 1.2 cm per year. Sastry (1971) has reported a rate of 14 cm/year at a station off Trombay. Sastry (1963) hypothesized that a larger part of the material deposited in the harbour is drawn from the various creeks bordering it, contradicting the earlier view of McClure (1930-31) that the material is of marine origin. Sastry & De Souza (1968), by comparing the height of the Cirus jetty from the sea bed in 1959 and in 1968, found two zones of deposition, one between 200 and 1200 feet from the shore-end of the jetty and the other between 2600 and 3270 feet. Between 1200 and 2600 feet the silt level remained stationary. Silt deposition during the course of these nine years was 7 feet between 400-600 feet away from the shore-end, and 12 feet at the caisson end.

The graph of activity plotted against depth of silt, for Station 22, shows a peak at 14 cm below the surface. This corresponds to the peak discharge of activity, i.e. in 1971. Activity below this depth tapers off, reaching stability at near-zero levels from 45 cm downwards. This would correspond to the years of silt deposition prior to commencement of discharge, *i.e.* pre-1964. From 1964 to 1971, *i.e.* in seven years, a silt deposit of 31 cm (45-14) has occurred. This gives a siltation rate of 4.4 cm per year at this station. Deposition of 14 cm of silt between 1971 and 1973-74 again gives a siltation rate of 4.7 cm/year,

At Station 13, the peak (1971) is only 4 cm below the surface. Activity levels approach zero at 42 cm below the surface. Thus 42 cm of silt have been deposited in 10 years, giving a siltation rate of 4.2 cm per year.

At Station 3, there is no well discerned peak, and near-zero levels of activity are reached at 29 cm below the surface. This amount of silt has been deposited in 10 years, giving a siltation rate of 2.9 cm/year.

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