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Fallout observations in India after the First French Atomic Test in Sahara

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ABSTRACT. The data on the airborne radioactive fallout and surface deposition of fallout in India after the French Atomic Test in Sahara on 13 February 1960, are reported. The increase in activity was observed during the period 16 February to 20 March. The maximum level of deposition at Bombay was about 170 millicuries per square kilometre, deposited between 17 and 18 February. This level was observed in the absence of rainfall. The air concentrations of fallout showed large fluctuations, with a maximum level of about 12 micro microcuries per cubic metre of air at Bombay between 19 and 20 February. Meteorological interpretations of the data are presented and estimates of total radiation dose from fallout from this test are carried out.

1. Introduction

Observations were made on the radioactive content of the air, and the deposition of radioactivity on the ground, at Bombay and other monitoring stations in India, to study the fallout from the radioactive cloud from the Atomic Test carried out by France at Reggane in Sahara, on 13 February 1960 at 1130 IST. The radioactive debris from the cloud was first observed at Bombay when the activity deposited on the ground between 15 and 16 February showed a sudden increase over the activity deposition rate during several weeks before the 15th. Subsequently a large increase in airborne activity was observed at Bombay as well as at all the other monitoring stations in India. This report gives data showing the activity levels at the various monitoring stations from 10 February to 20 March. The gamma-ray spectroscopic studies of the various samples carried out for the identification of freshly produced fission products are also presented. The various meteorological factors affecting the dispersion of radiaoctivity from the cloud have been discussed. An estimate of the radiation dose from fallout from this test, received by the population at Bombay, has been carried out on the basis of the observed data on the ground deposition of radioactivity and airborne radioactivity.

2. Airborne fallout data

The samples of airborne radioactive materials are collected daily from seven different stations in India (Vohra *et al.* 1958) and also from one station in the Sikkim State. These sampling stations are being operated by the Atomic Energy Establishment, Trombay. The geographical details of the stations are given in Table 1.

The samples are collected by sucking a known volume of air through a Hollingsworth and Vose No. H-70 filter paper. The gross beta activity of the residue collected on the filter paper is measured after allowing a period of 72 hours to elapse after collection, in order to enable the natural activity due to the radon and thoron products to decay almost completely. The data on gross beta activity of the samples collected at the above stations during the period 10 February to 20 March is shown in Fig. 1.

3. Surface deposition data

The samples of fallout-deposit on the ground are collected daily at Bombay using a stainless steel pot (Vohra *et al.* 1960) with a 1-cm layer of distilled water at the bottom.

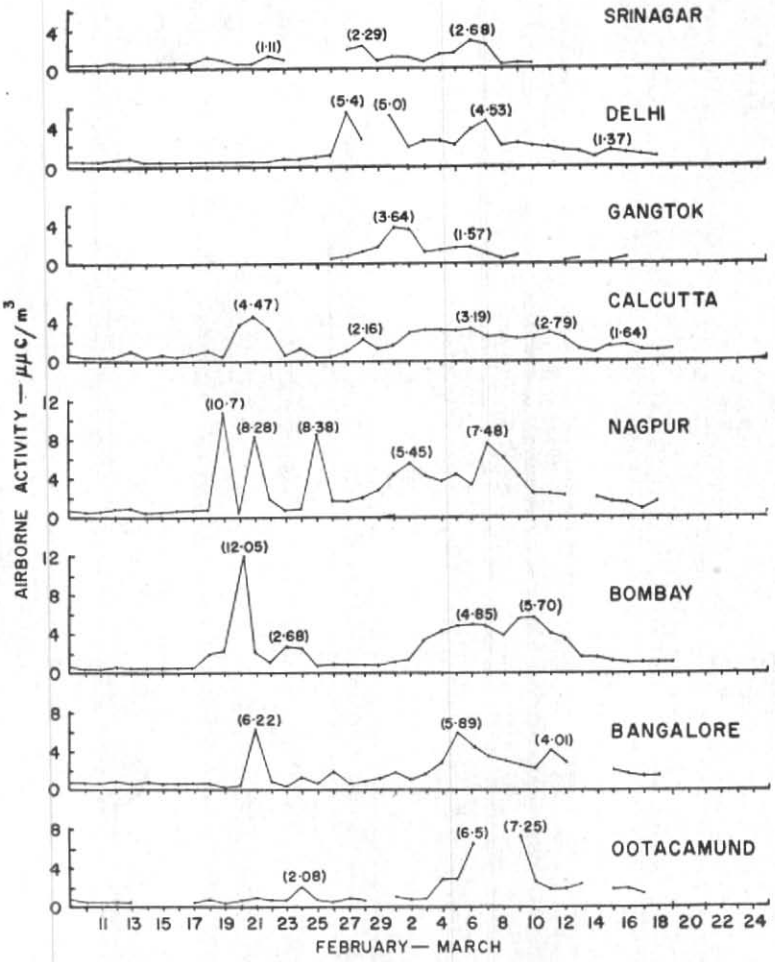

Fig. 1. Daily levels of airborne activity at different stations before and after the French Atomic Test

The pot is exposed to the free atmosphere daily for a period of 24 hours, keeping it in an open lawn at a height of about one metre above the ground. After the exposure the contents of the pot are concentrated onto a perspex planchet and the gross beta activity of the sample is measured using an end-window G.M. counter. Knowing the cross-sectional area of the pot the activity deposited per day on a square kilometre area of the ground is calculated. The activity deposited on each day from 10 February to 20 March is indicated on the graph in Fig. 2. The activity is expressed as microcuries per square kilometre area of the ground.

The highest level of deposited activity is about $1{\cdot}7 \times 10^5$ uc/km^2. It is significant that this deposition occurred in the absence of rainfall. The values of this order have earlier been observed at Bombay only during the periods of heavy rainfall following the testing of weapons (Vohra *et al.* 1960).

TABLE 1

Station	Altitude* (metres)	Latitude	Longitude
Bangalore	922	12°57′N	77°30′E
Bombay	Sea level	18°57′N	72°55′E
Calcutta	Sea level	22°34′N	88°25′E
Delhi	219	28°45′N	77°20′E
Gangtok	2000	27°12′N	88°23′E
Nagpur	311	21°12′N	79°04′E
Ootacamund	2235	11°23′N	76°40′E
Srinagar	1598	34°06′N	74°55′E

*Above mean sea level

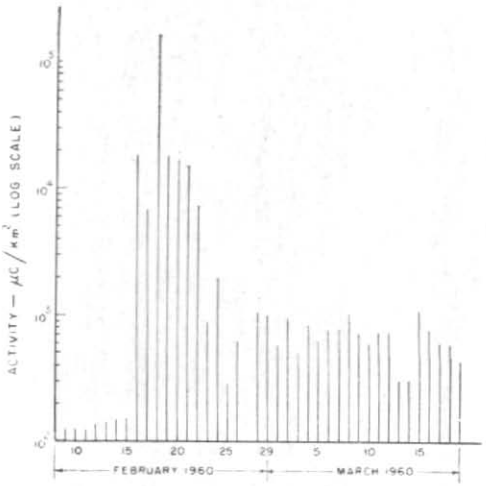

Fig. 2. Daily levels of deposited activity at Bombay before and after the French Atomic Test

4. Gamma-ray spectra of samples

In order to identify the various isotopes present in the fallout gamma-ray spectra of air dust samples and deposition samples were obtained using a 2·5 cm × 7·5 cm (dia) sodium iodide crystal detector and a 10-channel pulse height analyser. The peaks corresponding to the various isotopes characteristic of fresh radioactive fallout have been obtained in the spectra of air-dust and deposition samples. The isotopes identified in the gamma-ray spectra are Ba-140, La-140, Zr+Nb-95, Tc-99 m, Ce-141, and Te-132. The typical gamma-ray spectra of the samples are given in Appendix A.

5. Meteorological interpretation of the data

The fallout from the bomb cloud was first recorded at Bombay in the sample collected during the 24 hour period ending 1200 IST on 16 February. Since the weapon was exploded on 13 February at 1130 IST, it took about 72 hours or less for the cloud to be detected at Bombay which is approximately 3500 miles from Reggane (Lat. 26°45′ N, Long. 05°E)—the testing site in Sahara. This shows that the cloud of radioactive debris from the test must have moved with the westerlies in the troposphere at an average velocity of the order of 40 to 50 knots. The wind velocities of this order have been observed at Bombay during this period at altitudes above 30,000 feet.

The explosive power of the device has been reported to be about 60-70 kilotons (French Govt. Announcement appearing in *Times of India*, Bombay of 18 March 1960) which is probably large enough to raise the cloud to a height of about 40 thousand feet (Kellog *et al.* 1957). The height of the tropopause at latitudes of 20° to 30°N is about 50 to 55 thousand feet, and it is not likely that the cloud reached the stratosphere. As the cloud moved in the easterly direction from Sahara there must have been good vertical mixing responsible for the downward diffusion of the debris. The movement of the fallout debris from cloud in the lower levels of the atmosphere is influenced by the prevailing winds.

It is seen from the airborne fallout data that there are two fairly distinct periods of increase in activity, seen at most of the

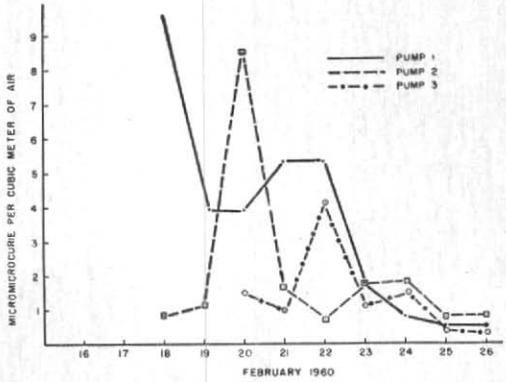

Fig. 3. Airborne radioactivity recorded at Bombay using three different pumps

stations. This may be explained to be due to the first and second rounds of the cloud around the globe. The other striking features of the airborne data are—(*i*) There have been marked fluctuations in the level of airborne activity during the first period of increase, particularly at Nagpur. (*ii*) The increase in airborne radioactivity was observed at Bombay and Calcutta for a period of 4-6 days during the first round of the cloud around the earth, and the increase persisted for 14-15 days during the second round, *i.e.*, after 1 March. (*iii*) The increase in airborne radioactivity has been more widespread during the second period.

It is difficult to explain the airborne radioactivity data on meteorological basis due to the fact that the radioactive matter in the air consists of particles of different sizes and different activity. The trapping of a particle of high activity on the filter paper will show a sudden increase in the airborne activity which may not be representative of the average concentration of radioactivity in the air.

The following experiment was carried out to study the nature of distribution of fallout particles in the air and to find an explanation for the observed features of airborne radioactivity. Three sampling pumps were run

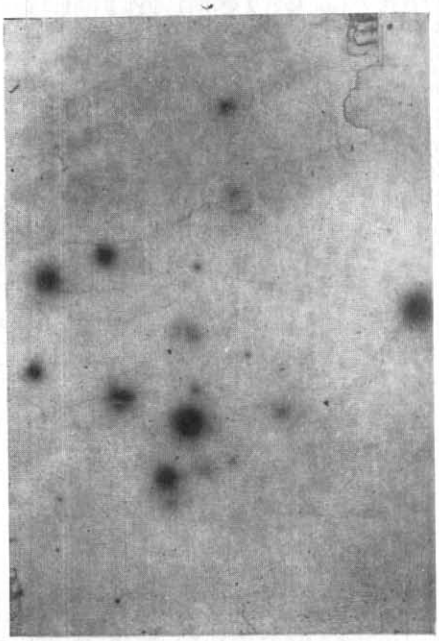

Fig. 4

X-ray film autoradiograph of a surface deposition sample (magnification X5·5) collected on 18 February 1960—5 days after the First French Atomic Test in Sahara on 13 February 1960. The autoradiograph shows that the sample contained a few very active particles which accounted for a major part of the activity.

simultaneously at the same site at Bombay, using the same type of filter paper for the collection of samples. Fig. 3 shows the levels of radioactivity recorded by each pump. Large variations in the airborne radioactivity are observed during the same period with different pumps. This shows that there has been a non-homogeneous distribution of radioactive particles in the air which is observed particularly during the first few days of fallout from the test.

The autoradiograph of the surface deposition sample collected on 18 February 1960 (Fig. 4) also shows that during the earlier stages of fallout the major part of the activity was confined to a few particles. This also suggests a non-homogeneous distribution of radioactive particles in the air.

The marked fluctuations in the airborne activity at Nagpur during the period 17 to 27

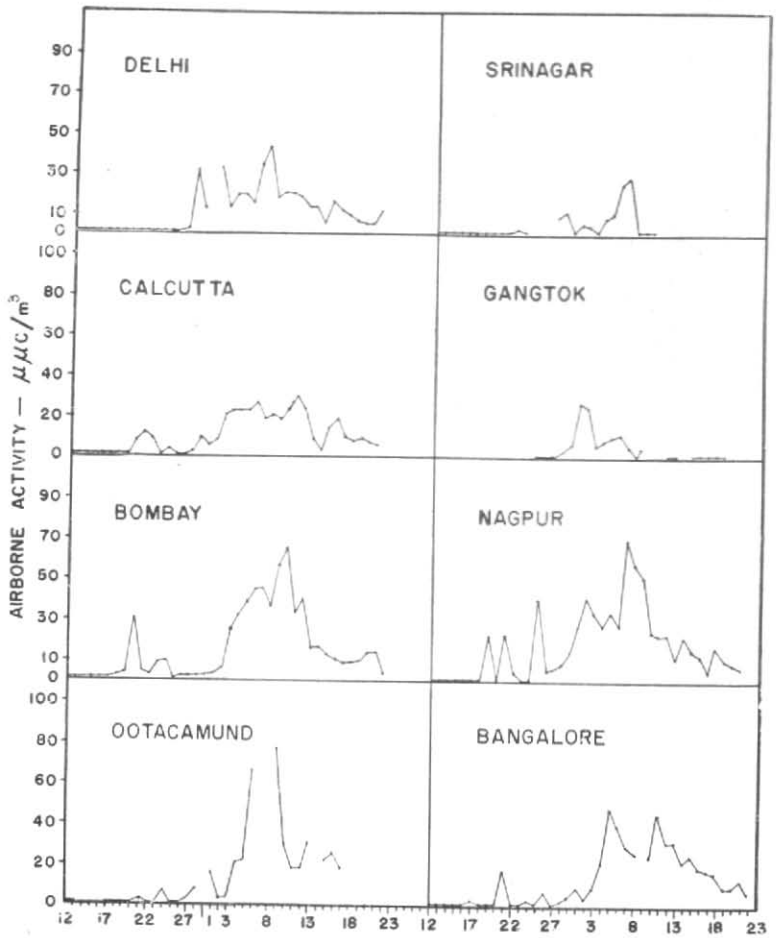

Fig. 5. Daily levels of activity corrected for decay

February (Fig. 1), the large activity peaks observed at Bombay between 19 and 21 February and at Bangalore between 20 and 22 February may be explained to be due to non-homogeneous distribution of fallout particles in the air, as shown above. This should also explain the low levels of airborne radioactivity at Bombay on 16 and 17 February in spite of large increase in fallout deposition on the ground, *i.e.*, the radioactive particles present in the air did get deposited on the ground but were not drawn into the air sampler.

The peak in surface deposition at Bombay during the period 16 to 22 February could be explained by the faster deposition of larger particles during the earlier period of fallout. During the latter stages of the cloud, although there is a peak in airborne activity, there is no large increase in surface deposition.

Fig. 5 shows levels of airborne activity on different days corrected for the decay of fission products in the air. The data in this figure would show a truer picture of the dispersion of fallout matter. The increase in

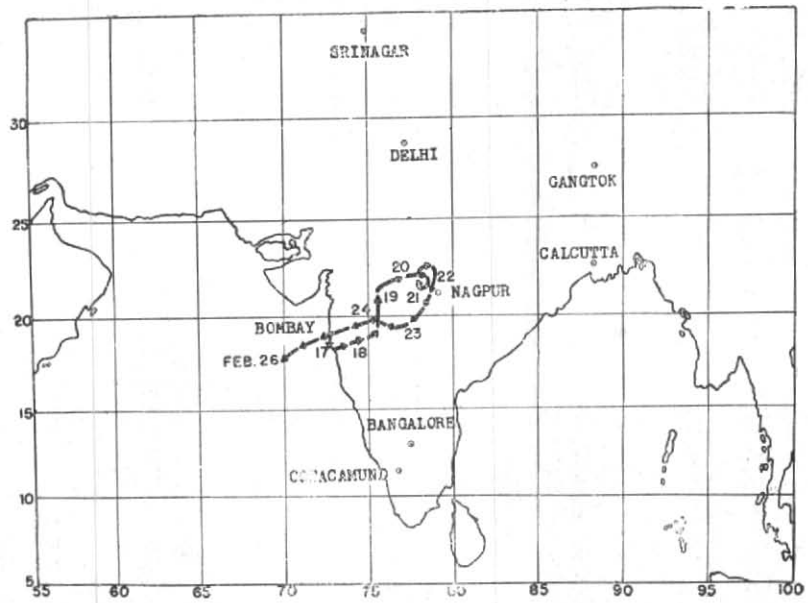

Fig. 5. Trajectory of an air mass from 16 February (1200 GMT) to 26 February (0000 GMT) at 5000 ft

airborne activity after 1 March (Fig. 5) is attributed to the second round of the cloud around the globe. It is seen that the airborne activity during the second round has been fairly widespread, *i.e.*, the increase is observed at all the stations, ranging from 11° to 34°N. There are no large sudden fluctuations and fallout matter appears to be more homogeneously mixed in the air. It is also observed that the bulk of fallout debris in the air has been greater during the second round of the cloud.

Fig. 6 gives the trajectory of an air mass at Bombay at an altitude of 5000 feet for the period 16 February (1200 GMT) to 26 February (0000 GMT). This trajectory was plotted to find out an explanation for the persistence of activity at Bombay during the period 17 to 25 February. This trajectory shows that the air mass starting from Bombay on 16 February returns back to Bombay on 25 February. This would probably explain the observed persistence of activity at Bombay.

6. Evaluation of radiation dose

An evaluation of the radiation dose from fallout from the test, received by the populations at any location, say Bombay, can be roughly carried out from the observed data on the ground deposition of radioactivity and the airborne radioactivity. Since the radioactivity from the test was confined within the troposphere the increase in radioactivity may be significant only for a period of 40-50 days. This is actually shown by the present data.

The contribution to the dose will be due to the following sources—(*a*) The external gamma dose to the human gonads due to the deposition of fission products on the ground, (*b*) The inhalation dose due to the presence of fission products in the air and (*c*) Dose due to the ingestion of fission products through food-chains.

The dose due to the deposition of fission products on the ground has been estimated for the period 16 February to 20 March,

taking into account the deposition on each day. It is estimated that the total infinity gamma dose delivered to a person standing in the open will be of the order of 1 mrem. If we allow a factor of 10 for shielding (to allow for the time spent inside the buildings and gonadal shielding factor) and weathering (U. N. Scientific Commitee 1958), the total dose is reduced to 0·1 mrem. The details of the evaluation of infinity gamma dose are given in Appendix B. About 70 per cent of the total dose is delivered within about 4 months. This dose is, however, very small compared to the dose one receives from exposure to natural radiation which is of the order of 100 mrem per year.

The dose delivered to the lung due to the inhalation of fission products has been evaluated on the assumption that 25 per cent of the fission products are retained inside the lungs and spend their entire beta decay energy inside the lungs. The infinity beta dose delivered to the lungs from inhalation on different days during the period 18 February to 20 March has been calculated for the airborne contamination observed at Bombay and the total dose is found to be about 0·9 mrem (Appendix C). This is also small compared to the lung dose received from the natural radioactivity in the air (U. N. Scientific Committee 1958).

The dose due to the ingestion of fission products through foods is expected to be small. However, this dose will be reduced considerably if the food materials are stored for a long time before consumption, since most of the activity from the tropospheric fallout is short lived. The biological retention of most of the fission product is very small, except strontium-90 and iodine-131. Strontium-90 contributes a negligibly small activity to tropospheric fallout. Iodine-131 will contribute only a small dose to the thyroid.

7. Acknowledgement

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Appendix A

Gamma-ray spectra of the samples for the identification of gamma-emitters in fallout

Figs. I and II give typical gamma-ray spectra of the samples of airborne dust and surface fallout collected after the French Atomic Test in Sahara on 13 February 1960. Fig. I gives the spectrum of the air filter sample collected during the period 17 to 20 February and counted on March 8. Fig. II gives the spectrum of a surface fallout sample collected on 17 February and counted on 26 February. These spectra have been obtained to identify the various fission products by studying their decay. The peaks in these spectra have been designated by comparison with the computed gamma-ray spectra of the fission-products-aggregates from plutonium-239 computed for two different times after fission, *i.e.*, 10 days and 30 days*. Tables I and II give lists of the isotopes, in the order of increasing gamma energy, which are likely to give a significant contribution to the gamma ray spectra of 10 and 30 days old fission-products-aggregates respectively.

TABLE I

Isotopes contributing to the gamma-ray spectrum of 10 days old fission products aggregates of Pu-239 fission

Isotope	Energy (MEV)	Half-life
Te-99m	0·14	5·9h
Ba-140	0·16	12·8d
Te-132	0·23	77h
I-131	0·364	8d
Ru-103	0·498	42d
Ba-140	0·540	12·8d
I-132	0·69	2·4h
Zr-95	0·722, 0·754	65d
Nb-95	0·75	35d
La-140	1·60	40h

TABLE II

Isotopes contributing to the gamma-ray spectrum of 30 days old fission products aggregates of Pu-239 fission

Isotope	Energy (MEV)	Half-life
Ce-141	0·145	30d
Ba-140	0·16	12·8d
Ba-140	0·30	12·8d
La-140	0·33	40h
I-131	0·364	8d
Ru-103	0·498	42d
Ba-140	0·540	12·8d
Zr-95	0·722, 0·754	65d
Nb-95	0·75	35d
La-140	1·60	40h

*Bjornerstedt, R., Low, K., and Ulvonas, S., *Products of Simultaneous Fission*, Forsvarets Forskningsanstalt, Avdelning 2, Intern Rapport B 150, 1956

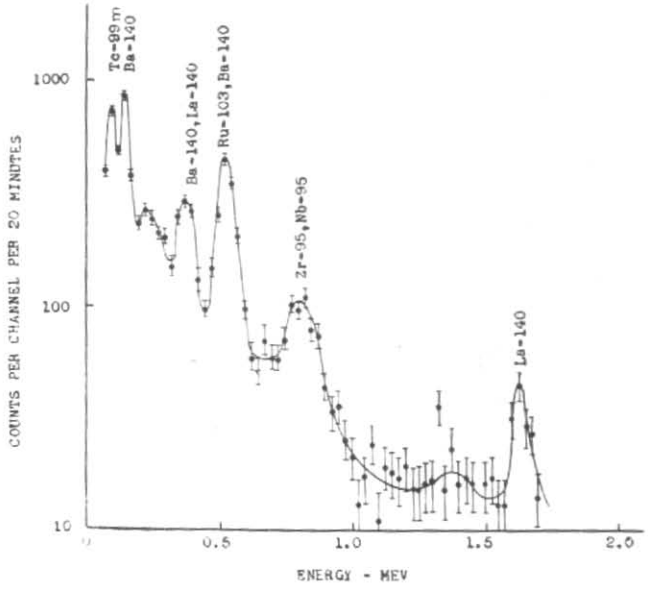

Fig. I

Collection period : 17-20 February 1960 Date of counting :8 March 1960

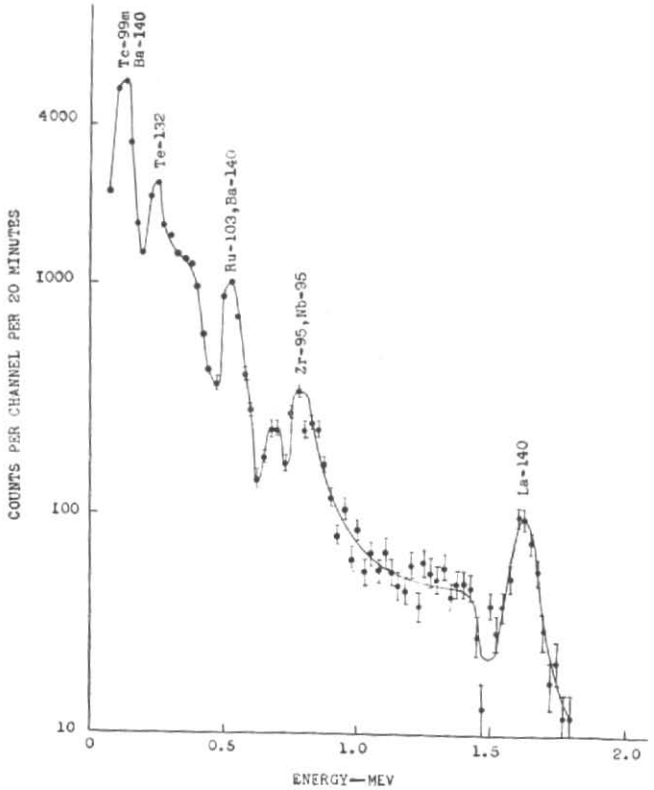

Fig. II

Date of collection : 17 February 1960 Date of counting : 26 February 1960

Appendix B

Estimation of total external Gamma Dose from the ground deposition of Radioactivity

The external gamma dose received in infinite time from the fallout deposited on the ground on each day after an atomic explosion can be calculated from the daily deposition data. The total dose from tropospheric fallout from any single test can be estimated by adding the infinity dose received on all days during which the fallout from the test occurred.

The dose from fallout-deposit on each day is calculated from the beta activity measurements of daily deposition samples. The dose computations are carried out as follows. The total beta disintegration rate of the activity deposited per square foot of the ground area is measured from pot collections. The total number of gamma disintegrations in infinite time from the fallout deposited per square foot is calculated from the beta disintegration rate*. From this, the total gamma dose delivered at 3 ft above the ground received by a person standing on a smooth infinite plain is calculated by the method given by Halden and Harley*. In calculating this dose it is assumed that the average energy of the gamma-ray photons from fission products is 0·54 mev and the beta activity deposited on the ground decays according to the $T^{-1.2}$ law. On this basis the doses calculated for fallout deposits on different days during the period 16 February to 20 March 1960 are given in Table I.

TABLE I

Date of sampling	β dpm/sq. ft on sampling day	Infinity gamma dose (urem)	Date of sampling	β dpm/sq.ft on sampling day	Infinity gamma dose(urem)
16-2-60	8940	63	2-3-60	235	7
17-2-60	2780	24	3-3-60	146	4
18-2-60	61400	634	4-3-60	229	7
19-2-60	7050	84	5-3-60	166	5
20-2-60	5390	72	7-3-60	455	15
21-2-60	4650	68	8-3-60	290	10
22-2-60	2130	35	9-3-60	222	8
23-2-60	258	5	10-3-60	170	6
24-2-60	548	11	12-3-60	394	16
25-2-60	98	2	14-3-60	152	6
26-2-60	222	5	15-3-60	269	11
27-2-60	29	0·7	16-3-60	216	9
28-2-60	297	7	18-3-60	300	14
29-2-60	276	7	19-3-60	120	6
1-3-60	156	4	20-3-60	46	2
				Total	1150

*Halden, N. A., Harley, J. H., *Method of calculating Infinity Gamma Dose from Beta Measurements on Gummed film*, NYO-4859, 1957, Health and Safety Laboratory, New York Operations Office, New York.

Appendix C

Estimation of the internal Beta Dose delivered to the lung in infinite time from inhalation of Airborne Radioactive Fallout

The lungs are the critical organs for the airborne beta activity from fallout. The total dose delivered to the lung in infinite time by the fission products retained in the lung through breathing, has been calculated from the observed concentrations of radioactive fallout products in the air, for the period of fallout from the First French Atomic Test, *i.e.*, 18 February to 20 March. The calculations are based on the following assumptions—(*i*) 25 per cent of the inhaled fission products are deposited inside the lungs, (*ii*) the particles will not be removed from the lungs during their radioactive life time, and (*iii*) the gamma dose to the lungs is negligible compared to beta dose.

The airborne activity has been expressed in the units of micro microcuries per cubic metre of air. The daily dose rate per micro microcuries per cubic metre at time t days after the explosion is given by

$$r(t) = \frac{V \alpha DE(1.6 \times 10^{-6} \text{ ergs/mev})}{M(100 \text{ erg/gm/rem})} \text{ rem/day/uuc}$$

where, V is the volume of air inhaled per day (=20 cubic metres), α is the fraction of activity retained (=0·25). D is the number of disintegrations per day per micro microcurie, E is the average beta energy (=0·4 mev) and M is the mass of lungs (=1000 grams).

The substitutions in the above equation give

$$r(t) = 10^{-7} \text{ rem/day/uuc/m}^3$$

The total dose received from time t to infinity is given by—

$$R(t) = \int_t^\infty r(t)\, t^{-1.2}$$

(assuming that the activity decreases according to $t^{-1.2}$ law)

$$= 5\, t\, r(t)$$
$$= 5\, t \times 10^{-7} \text{ rem/uuc/m}^3$$

Knowing the actual level of activity in the air on different days after the explosion, the values of $R(t)$ have been calculated for each day for the period 18 February to 20 March. The total dose received during this period at Bombay is estimated to be about 0·9 mrem.