NATURAL BACKGROUND RADIATION AND POPULATION DOSE DISTRIBUTION IN INDIA

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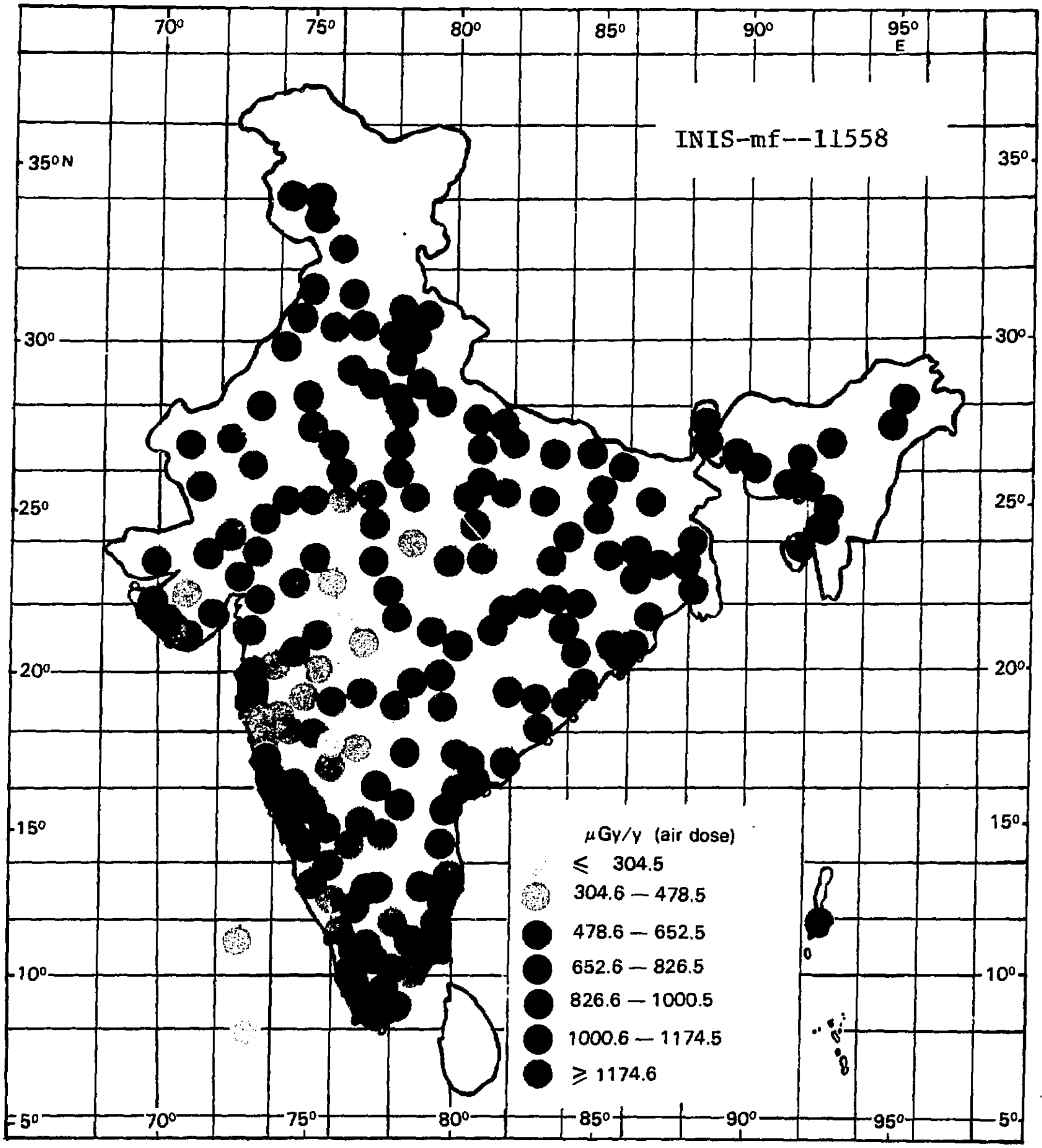

HEALTH PHYSICS DIVISION
BHABHA ATOMIC RESEARCH CENTRE
BOMBAY, INDIA

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GOVERNMENT OF INDIA
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ABSTRACT

A country-wide survey of the outdoor natural background gamma radiation levels has been made using mailed thermoluminescent dosimeters (TLDs). 214 locations scattered all over India—more than 90% being the weather stations of the Indian Meteorological Department—have been covered by this study over a continuous period of a year and the radiation levels monitored on a quarterly basis. Each "field TLD" was always accompanied by a "mail control TLD" and in all about 2800 measurements are available. The salient features of the results are:

(i) The air-kerma levels and the population doses in various states follow log-normal and normal distributions respectively.

(ii) The national average value for the air dose (air-kerma) is 775 ±370 (1σ) μGy/y.

(iii) The lowest air-kerma recorded is 0.23 mGy/y at Minicoy (Laccadive Islands) and the highest is 26.73 mGy/y at Chavra (monazite areas, Kerala).

(iv) There are significant temporal variations (even as high as ±40%) of the background radiation level at many locations and at least in 10 locations where radon/thoron measurements are available, these could be associated with the seasonal variations in radon/thoron levels.

(v) The mail control TLDs indicate a country-wide average value of 785±225 μGy/y for the air-kerma which can be considered to provide a truly national average value for the natural background radiation level in India.

(vi) The mean natural radiation per caput for the country works out to be 690±200 (1σ) μSv/y.

(vii) The natural radiation per caput seems to be maximum for Andhra Pradesh (1065±325 μSv/y) and minimum for Maharashtra (370±80 μSv/y).

(viii) The population dose from the external natural background radiation is estimated to be half a million person-Sievert.

(ix) Assuming ICRP risk factor, it can be estimated that just one out of the 43 cancer deaths occuring on an average per 100,000 population in India, can be attributed to the external natural background radiation.

1. INTRODUCTION

Nearly 75% of the radiation dose to the public arises from the natural background. Mankind has in fact evolved in a natural background radiation environment which can be basically divided into four components:

(i) cosmic rays orginating in outer space: it has a slight variation with the latitude but increases markedly with altitude.

(ii) primordial radioactivity in the rocks and soils: the outer half-metre layer of the earth's crust contributes effectively to almost all of this component of the background radiation at any location; the radioistopes responsible are daughter products of natural U and Th and K-40.

(iii) internal radioactivity distributed within the body in its tissues: the major contribution arises from K-40.

(iv) lung irradiation due to radon and thoron inhaled through air and their daughter products; this is generally higher inside a building because of restricted ventilation.

A knowledge of the population exposure to natural radiation and the general distribution of exposures is not only important for its own sake but also because: (i) it creates a proper perspective vis-a-vis the radiation insult caused by the nuclear industry and (ii) it helps in epidemiological studies correlating radiation exposure.

This report presents the results obtained in a nation-wide survey of the natural background radiation comprising of the components (i) and (ii) stated above using mailed thermoluminescent dosimeters (TLDs).

2. MONITORING LOCATIONS AND PROCEDURES

There are always problems of all sorts in a nation-wide survey (Brown 1984) and we thought it advantageous to choose the class A weather stations of the India Meteorological Department (IMD) for exposing the TLDs:

(i) All exposures could be done in a standard way inside the Stevenson Screen of these weather stations.

(ii) Data on rainfall, humidity and temperature could also be available for the period of monitoring—these might be useful to evaluate the season-dependant variations in the natural background radiation.

(iii) As these weather stations are maintained by a central government department, continued cooperation during the twelve months of monitoring could be assured by inter-departmental understanding.

(iv) Chances of tampering of the dosimeters (out of curiosity) is almost nil—a major constraint if dosimeters were to be exposed in individual homes.

With the kind cooperation of the IMD the study could be conducted in three phases of one year each, a different set of weather stations being chosen for each phase. Always a pair of TLDs was mailed to a volunteering station one of which was immediately mailed back to us to serve as "mail control TLD"; the other was referred as "field TLD". After 3 months a second pair was despatched to the same station and the old "field TLD" was received back along with the present "mail control TLD". At the end of the year, only a "mail control TLD" was sent to the station which came back with the last "field TLD". Thus a "field TLD" was always accompanied by a "mail control TLD". Any unusual extra exposure to the TLD during transit—for example by the presence of a radioactive package in the mail bag—could be easily noticed and the corresponding "field TLD" rejected.

At the end of the third and final phase, data were available for 202 stations; to this was added data for another 12 locations which are regularly monitored on a quarterly basis as a part of an environmental monitoring programme around nuclear installations in the country (Fig. 1). Each location is identified by a six digit number, the first digit indicating the phase during the which the location was monitored (Table 1), the next two digits identifying the state or union territory to which the station belongs (Table 2) and the last three digitis giving a serial number for the particular station.

3. THE ENVIRONMENTAL TLD

3.1 Dosimeter description

The environmental TL dosimeter used in this study consists of a pair of brass capsules filled with natural CaF_2 phosphor powder. The brass capsule has a wall thickness of 1.5 mm and the phosphor is contained in a cylindrical volume of 3 mm dia and 8 mm length. The phosphor powder (−80 +100 Tyler mesh size) is dispensed by a vibrator volume dispenser and the mass of powder filled in any capsule is typically 55 mg ± 2%(σ). These capsules are held firmly inside a plastic locket with a wall thickness of about 2 mm. The locket can be easily hung inside the Stevenson Screen at the weather stations using a hook provided in it. Fig 1a shows the photograph of the environmental TL dosimeter.

3.2 Performance characteristics

These have been dealt with in detail in an earlier report (Nambi et al 1983); the salient features have been summarised in table 3. In the Seventh International Environmental Dosimeter Intercomparison Project, these TLDs yielded estimates of environmental and laboratory exposures within ±10% of the true values (Gesell 1985).

3.3 Exposure Evaluation

The operation of an environmental TLD programme has been described in detail in an earlier report (Nambi 1979). The "irradiation history" of a "mail control TLD" or "field TLD" consists of successive periods with different rates of exposure as illustrated in Fig. 2.

The exposures (air-kerma) recorded by the mail control TLD (X_C) and field TLD (X_F) are given by

$$X_C = \dot{X}_S (t_{S1} + t_{S2}) + \dot{X}_T (t_{T1} + t_{T2}) + \dot{X}_I (t_{S1} + t_{S2} + t_{T1} + t_{T2}) \text{ .... } (1)$$

$$X_F = \dot{X}_S (t_{S1} + t_{S2}) + \dot{X}_T (t_{T1} + t_{T2}) + \dot{X}_F t_F + \dot{X}_I (t_{S1} + t_{S2} + t_{T1} + t_{T2}) \text{ .... } (2)$$

Where $\dot{X}_S$, $\dot{X}_T$ and $\dot{X}_F$ refer to air-kerma rates (μGy/day) during laboratory storage, mail transit and the field exposure; $\dot{X}_I$ is the self-irradiation rate in the phosphor due to its own radioactivity in equivalent air-kerma units. The pre-field storage, transit and post-field transit storage periods are represented by t with the subscripts s_1, t_1, t_2 and s_2 respectively. It should be noted that the value t_{T2} and t_{S2}

for the two TLDs need not be the same as any given field TLD is accompanied by independant mail control TLDs during the onward and return journeys. The average value of $\dot{X}_T$ calculated for the two mail control TLDs is used in eqn. (2) to get the value of $\dot{X}_F$. The values of $\dot{X}_S$ and $\dot{X}_I$ are determined independantly for a given storage facility and the given TL dosimeter package.

4. RESULTS AND DISCUSSIONS

4.1 Station-wise results and the national average

The mean and standard deviation of the four values of the field and mail control TLDs for each location are given in Table 4. The values have been corrected for the characteristics mentioned in Table 3. A multiplication factor of 8.7 has been employed to convert air exposure values (mR) into air-kerma units μGy). All quarterly readings are standardised to a period of 91.5 days and the mean of these have been listed in the Table. The national average value calculated for 365 days both from the field and transit doses have been given at the bottom of the Table. If the very high readings pertaining to the monazite areas of Kerala and Tamilnadu are excluded, a more realistic national mean of 765±300 μGy/year is obtained and the mail control TLDs of all stations lead to a national mean of 785±225 μGy/year. The standard deviation value obtained on the quarterly averages for each station is considered to reflect the seasonal variations in the environmental gamma dose-rate (sec.4.3); the standard deviation for the national mean is therefore obtained on the distribution of the annual air-kerma values of all stations. The close agreement between the values obtained from the field and mail control TLDs is taken as a measure of self-consistency in the dosimetric approach of the present study. Although the mail control TLD readings are individually quite low amounting to a few μGy only and consequently the reading inaccuracies rather high, the close agreement between the two bears also testimony to the satisfactory performance of our environmental TLDs.

It should be emphasised here that each dosimeter yields two estimates from the two capsules inside it. These are usually within ±2%

The loss of dosimeters either in transit or otherwise has been in the neighbourhood of 5–10% during all the three phases. There are also stations where only one quarterly measurement was ultimately obtained which are not included in the final analysis. Thus at the end of the study effectively 739×2 (=1478) field readings and 661×2 (=1322) mail control readings could be available; these 2800 quarterly measurements have lead to the national mean value of 775±370 μGy/y for the air-kerma in India due to outdoor natural background gamma radiation (terrestrial + cosmic and excluding monazite areas).

Yet another important aspect of the results is the more or less constant value obtained for the national mean in the three independent phases of the study (Table 5). This indicates that our monitoring locations are indeed uniformly distributed in each phase and the mean obtained for the natural background radiation adequately represents the national mean.

4.2 State-wise distribution of the radiation per caput of the populations

In order to obtain a perspective on the population doses over the entire country, the "field" results pertaining to each state/union territory have been separately considered along with the population figures known for 1981 in each monitoring location and the population weighted mean calculated for each state/union territory. These population-weighted mean exposure values are converted into whole body absorbed doses by using appropriate factors pertaining to house shielding, house occupancy and conversion of exposure units to μSv units for the natural background radiation.

The overall effect of the radioactivity in the building materials and their shielding efficiency to external radiations (terrestrial and cosmic) seem to give rise to an indoor to outdoor exposure ratio of 1.195 ± 0.243 (1σ) for four different types of houses considered here (Table 6). UNSCEAR (1982) reports values in the range of 0.70 to 1.8 for this ratio in various countries of the world with different types of houses taken into account and recommends a world-average value of 1.2.

The home occupancy factor for the Indian population weighted for five major categories is calculated to be 0.85 (Table 7). Hence the actual exposure received by each individual is $(1.195 \times 0.85 + 1.000 \times 0.15) = 1.17$ times the external exposure measured outdoors. O'Brien & Sanna (1978) have given absorbed dose rate conversion factors for scaled down MIRD Phantom with a weight of 58 kg and height of 163 cm and exposed to natural gamma rays. An average Indian adult is reported to be weighing 56.2 kg and 167 cm tall (ShivDatta et al 1982). We have used conversion factors of 5.21, 6.61 and 7.75 respectively for the scattered, uncollided and cosmic components of natural radiations spectrum to obtain μSv from mR values (O'Brien & Sanna 1978). Assuming the cosmic background radiation value appropriate to respective altitudes and a 15% scatter component to the terrestrial radiations (Beck 1972), the break-up of the three components of the natural background radiation and the weighted conversion factor, μSv/mR has been calculated for five major cities in India (Table 8) and the mean value is $6.83 \pm 3\%$; including the housing factor, the nett multiplying factor to be used to obtain μSv from mR values is $(6.83 \times 1.17 =)$ 8.0 [UNSCEAR (1982) recommends a value of 0.7 for the average value of the quotient of effective dose equivalent rate to absorbed dose rate in air for the terrestrial radiation exposure; in terms of μSv/mR ratio this works out to be 6.09; the ratio 6.83 evaluated in this study includes the cosmic component as *well*].

The population doses calculated for the individual states/union territories are presented in Table 9. The population wighted average for all the states excluding monazite areas, works out to be 690 μSv/y and this value has been used for the population of 3.511 million living in areas not covered by our dosimetric survey. Detailed dosimetry data are available for the monazite areas (Sunta et al 1981) and this has been entered separately in Table 9. The population dose for the entire country is 0.5 million person-Sievert per year and national mean for the radiation per caput is 690 μSv/y excluding the areas of the monazite deposits. (A higher value of 730 μSv/y is obtained when these high background areas are included).

4.3 Temporal variation of the natural background radiation at any given Location

As mentioned in Sec. 4.1 earlier, the deviations seen in the four quarterly values of the natural background gamma exposure is thought to arise from the seasonal variations in the radon, thoron emanations from soil into the air. This is because about 97% of the gamma dose from the Uranium series is due to the post-radon decay products while the post-thoron decay products account for about 60% of the total gamma dose from Thorium series.The concentrations of radon and thoron in the air depend on their emanation rate from the soil, meteorological and geographical factors and height above the ground surface. It is usually reported that these concentrations are maximum around early winter; the extents of variations are different however owing to the short half lives of thoron as compared to radon (Rangarajan et al 1974).

Their results have been plotted along with the TLD readings for ten cities in figs. 3 & 4. An interesting feature is the qualitative agreement between the trends in the variations of TLD readings and the radon-thoron daughter concentrations in air. It is also clearly seen that the ratio between the maximum to minimum is at least a factor lower than that for the radon-thoron daughter concentration indicating that the gamma dose contributed by these daughter products constitute only a fraction of the total external dose recorded by TLD. U, Th Series are reported to account for about 30% of the external γ-dose rate in India (Mishra & Sadashivan, 1971). It is however very interesting to find that TLDs are sensitive enough to reflect the seasonal variations in concentrations of radon-thoron daughters in ambient air. In some of the places at least e.g. Bangalore, Nagpur, Bombay and Trivandrum—the trends are nearly parallel to each other and there seems to be a possibility of obtaining a conversion factor to the lung dose due to radon, thoron daughters from TLD readings. These aspects will be dealt with in a later communication.

4.4 Nature of distribution of the air-kerma values and the population doses

One of the important findings in the present study has been that all air-kerma evaluations i.e. field and transit dose readings have always lead to log-normal distribution but the population weighted state averages are found to be normally distributed.

i) The air-kerma value of all the stations: median: 707 μGy/y; geom. deviation: 1.46 (fig. 5); the same is presented in a histogram in figure 6.

ii) The air-kerma value of all the transit exposures: median: 748 μGy/y; geom. deviation: 1.43 (figure 7).

iii) Seasonal variation of the air-kerma value at a location: Figure 8 gives results for typical cases of Raipur and Gangtok where the survey was extended for more than one year and therefore more data could be available for a log-normal analysis.

iv) Population-weighted state average: mean 688 μSv/y; Standard deviation: 200 (fig. 9).

5. CONCLUSIONS

Mishra and Sadasivan (1971) have projected a national average value of 70.7 mr/y (= 707 μGy/y) based on radioactivity analysis of soil samples from all over India and assuming uniform cosmic component of 28.7 mr/y. When altitude effects are properly accounted for, their soil activity-derived total external background radiation levels do match with our TLD data atleast in the case of five major cities (Nambi et al 1985). The present study has yielded a national average value of 775 μGy/y which should be considered more accurate as large number of locations have been covered and the measurements made include the actual cosmic and scattered components. The mean, population weighted mean and the median values of the air-kerma in individual states/union territories have been presented in Table 10. If one excludes the monazite areas, it is seen that the two populous states of Andhra Pradesh and Uttar Pradesh have nearly twice as much natural background radiation levels prevalent in Maharashtra having also a significant population. The lowest air-kerma value is encountered in Laccadive islands. The TLD results in general seem to be consistent with the various geological units of the Indian land Mass (Nambi et al 1985). The Deccan Plateau, consisting mostly of basalts of very low primordial radioactivity has shown the lowest radiation levels in ambient air; the monazite regions of the western and eastern coasts at the southern most points and the regions of metamorphic and granitic rocks of northern and north eastern region of Archaen and unclassified rocks have shown the highest radiation levels. A very detailed study correlating the radioactivity levels in different rock formations of Indian Geology with the TLD recorded exposure data will be published separately (Sankaran et al 1986).

A comparision of the air-kerma values for various countries as summarised by Beninson et al (1977) with the presently obtained values for India is presented in Table 11 (cosmic ray dose rates ranging between 280 and 300 μGy/y have been added to the terrestrial dose rates quoted by Beninson). Table 12 presents a comparison of the Indian Radiation Per Caput value with those reported for USA and UK for the natural background external radiation.

Assuming the ICRP risk factor of 1.25×10^{-2} Sv^{-1} (ICRP 1977) the natural background external radiation induced population dose of 501655 person Sv (Table 9) is expected to result in just one excess death per 100,000 population annually. This is hardly 2% of the total cancer fatalities and 0.06% of total deaths occuring annually in the country (Table 13).

Acknowledgements

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TABLE 1. CODING LIST FOR THE DIFFERENT PHASES OF THE SURVEY

Code no. for the phase	Period of survey
0	continuing routine monitoring
1	April 1981 — March 1982
2	April 1982 — March 1983
3	April 1983 — March 1984

TABLE 2. CODING LIST FOR STATES AND UNION TERRITORIES

State/Union territory	code no.	Area in 10^4 km^2	No. of locations monitored
Jammu and Kashmir	01	22.224	7
Himachal Pradesh	02	5.564	2
Punjab	03	5.036	3
Haryana	04	4.422	2
Delhi	05	0.149	2
Uttar Pradesh	06	29.441	20
Bihar	07	17.388	11
Sikkim	08	0.730	2
Arunachal Pradesh	09	8.358	—
Nagaland	10	1.653	—
Manipur	11	2.236	—
Mizoram	12	2.109	—
Tripura	13	1.048	2
Meghalay	14	2.249	3
Assam	15	7.852	6
West Bengal	16	18.784	8
Orissa	17	15.578	10
Madhya Pradesh	18	44.284	20
Rajasthan	19	34.221	14
Gujarat	20	19.598	14
Maharashtra	21	30.776	24
Andhra Pradesh	22	27.681	16
Karnataka	23	19.177	16
Goa	24	0.127	2
Kerala	25	3.886	6
Tamilnadu	26	13.007	17
Daman	27	0.127	1
Diu	28	0.127	1
Pondicherry	29	0.048	1
Andaman	30	0.829	1
Laccadiv	31	0.003	3

TABLE 3. PERFORMANCE CHARACTERISTICS OF THE ENVIRONMENTAL TLD

Characteristics	Performance
1. a) Energy dependence	±20% between 50 and 1250 keV
b) Environmental exposure response	±1% of the true exp. using Ra-226 calibr.
2. Fading	3% in 3 months of continuous exp.
3. Directional response	nearly isotropic
4. Self dose-rate	26.8 μGy/y
5. Precision	±5%
6. Accuracy (1 - 10 mR range)	±10%

TABLE 4. FIELD AND MAIL CONTROL TLD RESULTS FOR ALL STATIONS

(Quarterly averages)

Sr. No.	Station (State Code)	Air-kerma micro-Gy/quarter		Transit dose in micro-Gy/day	
		Mean	S.D.	Mean	S.D
1.	Adilabad (22)	288.	0.	4.39	.00
2.	Agartala(13)	168.	0.	2.35	.00
3.	Agra (06)	195.	0.	2.04	.82
4.	Ahmedabad (20)	141.	5.	1.39	.61
5.	Akola (21)	87.	26.	2.09	.71
6.	Alibaug (21)	95.	25.	2.09	.74
7.	Aligarh (06)	284.	2.	2.35	.00
8.	Allahabad (06)	292.	41.	3.13	.00
9.	Alleppey (25)	177.	37.	2.70	.30
10.	Ambala (04)	227.	40.	2.28	.34
11.	Ambikapur (18)	262.	73.	2.20	.48
12.	Amnidivi (31)	87.	17.	1.65	.12
13.	Amritsar (03)	191.	27.	1.33	.48
14.	Anantpur (22)	154.	15.	1.57	.30
15.	Atalgarh (01)	253.	36.	2.87	.12
16.	Aurangabad (21)	93.	5.	1.13	.25
17.	Bahraich (06)	251.	7.	2.70	.45
18.	Balassore (17)	140.	49	2.70	.48
19.	Banaras (06)	237.	10.	3.13	.00
20.	Banda (06)	232.	51.	2.87	.00
21.	Bangalore—A (23)	130.	0.	1.45	.10
22.	Bangalore—B (23)	197.	8.	1.91	.00
23.	Bankura (16)	283.	45.	3.07	.58
24.	Bapatla (22)	130.	28.	2.22	.25
25.	Baramati (21)	102.	49.	2.29	.93
26.	Bareilly (06)	228.	24.	1.91	1.20
27.	Barmer (19)	180.	18.	1.89	.29
28.	Baroda (20)	143.	23.	1.76	0.4
29.	Batote (01)	221.	29.	2.07	.11
30.	Behrampur (16)	240.	55.	2.91	.32
31.	Belgaum—A (23)	170.	5.	—	—
32.	Belgaum—B (23)	128.	25.	2.35	1.02
33.	Bellary (23)	179.	61.	2.74	.66

TABLE 4. FIELD AND MAIL CONTROL TLD RESULTS FOR ALL STATIONS (Contd.)

(Quarterly averages)

Sr. no.	Station (State Code)	Air-kerma in micro-Gy/quarter		Transit dose in micro-Gy/day	
		Mean	S.D.	Mean	S.D
34.	Betul (18)	293.	50.	2.06	.18
35.	Bhagalpur (07)	338.	57.	2.63	.19
36.	Bhavnagar (20)	125.	37.	1.70	.18
37.	Bhilwara (19)	170.	34.	2.44	.42
38.	Bhopal (18)	127.	19.	1.48	.12
39.	Bhuj (20)	139.	15.	1.48	.54
40.	Bhuntar (02)	302.	48.	2.70	.40
41.	Bhuvaneshwar (17)	180.	20.	2.20	1.00
42.	Bijapur (23)	119.	41.	1.94	.69
43.	Bikaner (19)	144.	13.	2.33	.29
44.	Bilaspur (18)	200.	30.	2.22	.57
45.	Bir (21)	129.	21.	2.04	1.03
46.	Bombay—A (21)	108.	19.	.52	.00
47.	Bombay—B (21)	89.	8.	1.45	.05
48.	Brahmapuri (21)	197.	36.	2.11	.44
49.	Calcutta—A (16)	181.	9.	2.18	.25
50.	Calcutta—B (16)	220.	18.	1.04	.00
51.	Calicut (25)	122.	1.	1.33	.18
52.	Champa (18)	207.	46.	2.58	.63
53.	Chandrapur (21)	228.	22.	2.41	.53
54.	Chavra (25)	1305.	0.	2.61	.00
55.	Cherapunj (14)	138.	26.	2.50	.40
56.	Chingleput (26)	250.	41.	—	—
57.	Chitradurga (23)	128.	7.	2.44	.33
58.	Churu (19)	177.	31.	2.09	.19
59.	Cochin (25)	143.	10.	3.07	.69
60.	Coimbatore (26)	170.	25.	2.41	.46
61.	Cooch Bihar (16)	210.	21.	2.33	.30
62.	Cuddalore (26)	124.	2.	1.83	.38
63.	Dahanu (21)	110.	23.	2.46	.54
64.	Daltanganj (07)	243.	38.	3.00	.44
65.	Daman (27)	133.	11.	1.30	.00
66.	Darbhanga (07)	212.	51.	2.44	1.31
67.	Deesa (20)	168.	35.	2.24	.40
68.	Dehradun (06)	217.	29.	1.26	.46
69.	Devgad (21)	178.	14.	2.23	1.05
70.	Dhanbad (07)	170.	34.	1.89	.38
71.	Dharamsala (02)	252.	33.	2.75	.20
72.	Dhubri (15)	217.	0.	1.57	.00
73.	Dibrugharh (15)	187.	40.	2.35	.62
74.	Diu (28)	108.	13.	2.29	.35
75.	Dohad (20)	244.	24.	2.87	.00
76.	Fatehpur (06)	264.	88.	2.41	.62
77.	Ferozpur (03)	225.	47.	2.96	.63
78.	Gadag (23)	173.	15.	1.11	.57
79.	Gangtok (08)	282.	32.	2.70	.00
80.	Gannavaram (22)	121.	13.	1.91	.62
81.	Gauhati (15)	254.	22.	2.44	.37
82.	Gaya (07)	184.	39.	1.77	.75

TABLE 4. FIELD AND MAIL CONTROL TLD RESULTS FOR ALL STATIONS (Contd.)

(Quarterly averages)

Sr. no.	Station (State Code)	Air-kerma in micro-Gy/quarter Mean	S.D.	Transit dose in micro-Gy/day Mean	S.D
83.	Gonda (06)	315.	2.	3.39	.00
84.	Gopalpur (17)	648.	40.	2.06	.25
85.	Gorakhpur (06)	241.	0.	1.22	.62
86.	Gulbarga (23)	82.	14.	2.18	.17
87.	Gulmarg (01)	211.	25.	2.46	.08
88.	Guna (18)	182.	24.	1.96	.39
89.	Gwalior (18)	190.	18.	1.33	.44
90.	Hardoi (06)	280.	47.	3.18	.82
91.	Haripara (01)	215.	5.	2.35	.33
92.	Harnai (21)	89.	34.	2.39	.63
93.	Honavar (23)	169.	25.	1.83	.55
94.	Hoshangabad (18)	231.	40.	2.61	.00
95.	Hyderabad (22)	343.	25.	2.12	.28
96.	Idar (20)	321.	86.	2.61	.89
97.	Indore (18)	93.	8.	1.15	.26
98.	Jabalpur (18)	202.	30.	1.76	.29
99.	Jaduguda (07)	200.	18.	1.76	.51
100.	Jagdalpur (18)	245.	4.	1.33	.32
101.	Jaipur (19)	172.	14.	2.61	.00
102.	Jaisalmer (19)	144.	4.	1.26	.15
103.	Jalgaon (21)	124.	9.	1.86	.61
104.	Jamshedpur (07)	236.	40.	—	—
105.	Jarsuguda (17)	302.	4.	2.20	.63
106.	Jeur (21)	148.	12.	1.30	.00
107.	Jhansi (06)	306.	80.	3.24	.23
108.	Jodhpur (19)	168.	10.	1.39	.00
109.	Kadma (07)	242.	29.	2.38	.41
110.	Kailasnagar (13)	175.	42.	2.28	.48
111.	Kakinada (22)	178.	12.	2.00	.37
112.	Kalpakkam (26)	277.	36.	2.65	.64
113.	Kammam (22)	283.	53.	2.87	.41
114.	Kanyakumari (26)	1281.	144.	2.89	.49
115.	Karaikkal (29)	232.	26.	1.07	.50
116.	Karwar (23)	136.	28.	2.11	.58
117.	Keshod (20)	199.	5.	2.00	.54
118.	Khandwa (18)	115.	18.	2.33	.29
119.	Kharagpur (16)	197.	19.	—	—
120.	Kodaikkanal (26)	152.	9.	1.48	.00
121.	Kolhapur (21)	122.	38.	1.87	.57
122.	Koraput (17)	407.	54.	2.76	1.00
123.	Kota (19)	109.	20.	1.74	.25
124.	Kupwara (01)	216.	38.	3.65	1.60
125.	Kurnool (22)	166.	27.	1.98	.60
126.	Lakhimpur-north (15)	197.	17.	2.37	.04
127.	Lucknow (06)	265.	0.	2.00	.49
128.	Machalipattanam (22)	182.	16.	2.31	.18
129.	Madras—A (26)	231.	10.	1.00	.06
130.	Madras—B (26)	176.	3.	1.91	.00
131.	Madurai (26)	259.	45.	2.70	.83

TABLE 4. FIELD AND MAIL CONTROL TLD RESULTS FOR ALL STATIONS (Contd.)

(Quarterly averages)

Sr. no.	Station (State Code)	Air-kerma in micro-Gy/quarter		Transit dose in micro-Gy/day	
		Mean	S.D.	Mean	S.D
132.	Mainpuri (06)	287.	53.	2.72	.75
133.	Malegaon Camp (21)	136.	14.	2.15	.47
134.	Mangalore (23)	115.	19.	1.48	.23
135.	Marmagoa (24)	168.	2.	1.17	.31
136.	Mercara (23)	104.	33.	2.48	.11
137.	Minicoy—A (31)	56.	9.	—	—
138.	Minicoy—B (31)	83.	5.	1.54	.26
139.	Moradabad (06)	228.	46.	2.09	.38
140.	Mukhim (06)	347.	44.	2.78	.14
141.	Mysore (23)	163.	20.	2.26	.48
142.	Nagapattinam (26)	141.	14.	1.83	.30
143.	Nagpur (21)	121.	13.	1.60	.35
144.	Najibabad (06)	190.	11.	2.74	.36
145.	Narora (06)	260.	23.	1.89	.99
146.	Nasik (21)	92.	13.	1.61	.43
147.	Nellore (22)	201.	14.	1.25	.36
148.	New Delhi—A (05)	181.	11.	2.13	.68
149.	New Delhi—B (05)	180.	14.	1.39	.44
150.	Nizamabad (22)	370.	44.	4.12	.73
151.	Okha (20)	135.	5.	2.61	.00
152.	Omrai (14)	184.	41.	2.39	.36
153.	Ongole (22)	204.	28.	2.46	.19
154.	Palayamkottai (26)	219.	35.	3.57	1.01
155.	Pamban (26)	118.	19.	2.48	.40
156.	Panaghar (16)	141.	5.	2.06	1.25
157.	Panjim (24)	158.	16.	1.60	.43
158.	Paradeep (17)	182.	9.	1.22	.37
159.	Parbhani (21)	134.	20.	2.03	.75
160.	Patiala (03)	160.	34.	1.94	.44
161.	Patna (07)	244.	20.	2.09	1.15
162.	Pattambi (25)	139.	11.	2.41	.31
163.	Phalodi (19)	148.	7.	2.15	1.06
164.	Phulbani (17)	322.	94.	3.63	.28
165.	Porbondar (20)	134.	21.	1.94	.49
166.	Port Blair (30)	123.	12.	1.70	.80
167.	Pune (21)	83.	11.	1.25	.18
168.	Puri (17)	338.	35.	3.28	.43
169.	Quazigund (01)	205.	26.	2.63	.48
170.	Radhanpur (20)	187.	10.	2.38	.13
171.	Rahuri (21)	106.	20.	1.87	.54
172.	Raichur (23)	357.	48.	2.78	.70
173.	Raigarh (18)	301.	42.	1.74	.00
174.	Raipur—A (18)	154.	12.	1.54	.61
175.	Raipur—B (18)	177.	32.	2.09	.55
176.	Rajkot (20)	80.	19.	1.36	.20
177.	Ramagundan (17)	156.	13.	1.74	.53
178.	Ranapratap Sagar (19)	135.	38.	1.67	.13
179.	Ranchi (07)	315.	73.	2.64	.10
180.	Ratlam (18)	131.	21.	2.20	.50

TABLE 4. FIELD AND MAIL CONTROL TLD RESULTS FOR ALL STATIONS (Contd.)

(Quarterly averages)

Sr. no.	Station (State Code)	Air-kerma in micro-Gy/quarter Mean	S.D.	Transit dose in micro-Gy/day Mean	S.D
181.	Ratnagiri (21)	146.	12.	1.17	.46
182.	Raxaul (07)	225.	48.	2.35	.38
183.	Rohtak (04)	210.	32.	2.70	.71
184.	Sagar (18)	121.	43.	2.47	.22
185.	Salem (26)	86.	26.	1.98	.48
186.	Sambalpur (17)	190.	34.	2.39	.23
187.	Satana (18)	193.	28.	1.91	.43
188.	Shantiniketan (16)	169.	37.	2.35	1.11
189.	Shilong (14)	199.	12.	1.52	.43
190.	Shimoga (23)	141.	3.	2.39	.53
191.	Shivpuri (18)	220.	55.	1.44	.18
192.	Sikar (19)	173.	18.	2.31	.31
193.	Silchar (15)	203.	19.	1.22	.00
194.	Solapur (21)	74.	1.	1.13	.26
195.	Sriganga Nagar (19)	228.	21.	2.78	.59
196.	Srikakulam (22)	352.	54.	2.70	.24
197.	Srinagar (01)	204.	24.	2.37	.11
198.	Surat (20)	120.	32.	1.83	.55
199.	Tarapur (21)	119.	12.	1.46	.23
200.	Tedang (08)	239.	28.	2.87	.90
201.	Tehri (06)	119.	25.	2.76	.55
202.	Tezpur (15)	205.	21.	1.65	—
203.	Thondi (26)	119.	27.	2.50	.68
204.	Tonk (19)	234.	54.	2.44	.86
205.	Trichirappalli (26)	179.	7.	1.48	.26
206.	Trivandrum (25)	226.	23.	1.78	.64
207.	Tuticorin (26)	138.	33.	2.48	.57
208.	Udaipur (19)	179.	16.	2.72	1.17
209.	Umaria (18)	208.	38.	2.41	.61
210.	Vellore (26)	164.	25.	2.20	.74
211.	Veraval (20)	84.	16.	1.70	.06
212.	Vishakapattinam—A (22)	226.	18.	2.09	.31
213.	Vishakapattinam—B (22)	240.	13.	1.51	.59
214.	Vishakapattinam—C (22)	229.	13.	1.57	.35

Field results

Annual average : 806. ± 524. micro-Gy/year
Population weighted annual average : 658. ± 259. micro-Sv/year
Annual average : 764. ± 297. micro-Gy/year
Population weighted annual average : 656. ± 240. micro-Sv/year
(The last two averages have been computed excluding monazite areas)

Mail control results

Annual average : 784. ± 224. mirco-Gy/year
Annual average : 782. ± 224. micro-Gy/year
(The last average has been computed excluding monazite areas)

TABLE 5. VARIATIONS IN THE NATIONAL MEAN VALUE FOR THE NATURAL BACKGROUND RADIATION DURING THE VARIOUS PHASES OF THE STUDY

Phase of study	Total No. of met. stations at the end of the phase	National mean* for natural background radiation ± 1 σ (μGy/y)
1	71	730 ± 315
2	136	715 ± 235
3	202	770 ± 270
0-3	214	770 ± 300

* excluding the monazite area

TABLE 6. INDOOR/OUTDOOR EXPOSURE RATIO IN TYPICAL HOUSES IN INDIA

Sr. No.	Place (No. of houses monitored)		Type of house (Bldg. material)	Indoor/outdoor exp.* ratio ± 1σ
1.	Monazite areas, Kerala	(952)	hut (clay, palmleaves, wood)	0.82 ± 0.10
2.	Bombay	(5)	Concrete	1.14 ± 0.12
3.	Hyderabad	(3)	Cement, Granite	1.40 ± 0.18
4.	Alwaye	(2)	Bricks, mortar	1.42 ± 0.20
			Mean	1.195 ± 20%

*(terrestrial + cosmic) exposure

TABLE 7. CATEGORIES OF INDIAN POPULATION AND HOUSE OCCUPANCY FACTORS

Sr. No.	Category	% of population	House Occupancy factor
1.	Women	44	1.00
2.	Children<5 yrs	14	1.00
3.	Old people (> 60 yrs)	6.5	1.00
4.	Agricultural Labourers	25	0.50
5.	Rest	10.5	0.75
		Weighted Mean	*0.85*

TABLE 8. COMPONENTS OF THE NATURAL BACKGROUND RADIATION IN MAJOR CITIES OF INDIA AND THE WEIGHTED CONVERSION FACTOR, μSv/mR

	Natural background mrad/y			Components (%)			
City (altitude)	Total (measured)	Cosmic (assumed)	Terrestrial + Scattered (total-Cos)	Uncollided terrestrial	Scattered	Cosmic	Weighted C.F.* μSv/mR
Bombay (sea-level)	48.4	28.0	20.4	36	6	58	7.03
Calcutta (sea-level)	81.0	28.0	53.0	55	10	35	6.62
Delhi (216 m)	70.0	31.0	39.0	48	8	44	6.68
Madras (sea-level)	79.0	28.0	51.0	55	10	35	6.62
Bangalore (921 m)	82.5	44.0	38.5	40	7	53	6.94
							Mean 6.83 ± 3%

* C.F. for uncollided terrestrial component 6.66
C.F. for scattered component 5.21
C.F. for cosmic component 7.75

TABLE 9. POPULATION DOSE DISTRIBUTION IN VARIOUS STATES AND UNION TERRITORIES OF INDIA

Sr. No.	State/Territory	Population as on 1981 (millions)	Natural radiation per caput $\mu Sv\ y^{-1}$	Population Dose Person $Sv\ y^{-1}$
1.	Andaman	0.188	450	85
2.	Andhra Pradesh	53.404	1065	56875
3.	Assam	19.903	820	16320
4.	Bihar	69.823	875	61905
5.	Daman	0.361	490	175
6.	Delhi	6.196	665	4120
7.	Diu	0.361	400	145
8.	Goa	0.361	600	215
9.	Gujarat	33.961	490	16640
10.	Haryana	12.851	800	10280
11.	Himachal Pradesh	4.238	960	4070
12.	Jammu & Kashmir	5.982	755	4515
13.	Karnataka	37.044	585	21485
14.	Kerala (except monazite)	25.303	595	15055
15.	Laccadiv	0.402	285	110
16.	Madhya Pradesh	52.132	590	30760
17.	Maharashtra	62.694	370	23190
18.	Meghalaya	1.328	720	955
19.	Orissa	26.272	855	22465
20.	Pondicherry	0.604	855	515
21.	Punjab	16.670	685	11420
22.	Rajasthan	34.103	610	20805
23.	Sikkim	0.316	1040	330
24.	Tamil Nadu (except monazite areas)	48.198	705	33980
25.	Tripura	2.060	620	1275
26.	Utter Pradesh	110.858	910	100880
27.	West Bengal	54.486	740	40320
28.	Monazite areas	0.200	5760	1150
29.	Areas not covered	3.511	690	2425
	Total	*683.810*		*501655*

All India Average Radiation Per Caput : 690 $\mu Sv\ y^{-1}$

TABLE 10. AVERAGE EXTERNAL RADIATION BACKGROUND LEVELS IN THE INDIVIDUAL STATES AND UNION TERRITORIES OF INDIA

State/Union Territory	Air-kerma in micro-Gy/year		Log-normal analysis			Radiation per kaput in micro-Sv/year	
	Mean	S.D.	G.M. in μGy/y	G.S.D.	Corr. coef.	Mean	S.D.
Andaman	492.	0.	—	—	—	453.	0.
Andhra Pradesh	917.	313.	868.	1.41	0.99	1064.	326.
Assam	842.	94.	838.	1.11	0.94	819.	118.
Bihar	948.	204.	928.	1.23	0.97	876.	208.
Daman	530.	0.	—	—	—	488.	0.
Delhi	721	2.	721.	1.00	—	663.	2.
Diu	433.	0.	—	—	—	398.	0.
Goa	651.	27.	651.	1.05	—	600.	25.
Gujarat	635.	255.	594.	1.44	0.98	491.	113.
Haryana	874.	49.	874.	1.06	—	799.	45.
Himachal Pradesh	1108.	142.	1103.	1.14	—	957.	131.
Jammu and Kashmir	872.	67.	869.	1.07	0.89	756.	68.
Karnataka	623.	247.	589.	1.37	0.95	584.	187.
Kerala	1408.	1873.	897.	2.14	0.84	651.	590.
	(646.)	(166.)	(627.)	(1.27)	(0.96)	(593.)	(175.)
Laccadive	301.	66.	293.	1.26	0.94	287.	59.
Madhya Pradesh	770.	231.	735.	1.37	0.98	590.	197.
Maharashtra	485.	133.	466.	1.32	0.98	371.	78.
Meghalaya	694.	127.	681.	1.21	0.97	718.	147.
Orissa	1146.	625.	1022	1.62	0.96	853.	354.

Note : The data within parantheses have been computed excluding monazite areas

— Insufficient data for analysis.

TABLE 10. AVERAGE EXTERNAL RADIATION BACKGROUND LEVELS IN THE INDIVIDUAL STATES AND UNION TERRITORIES OF INDIA (Contd.)

State/Union Territory	Air-kerma in micro-Gy/year Mean	S.D.	Log-normal analysis G.M. in μGy/y	G.S.D.	Corr. coef.	Radiation per kaput in micro-Sv/year Mean	S.D.
Pondicherry	927.	0.	—	—	—	853.	0.
Punjab	769.	129.	756.	1.19	1.00	685.	91.
Rajasthan	675.	134.	662.	1.21	0.97	609.	112.
Sikkim	1043.	—	1040	1.13	—	1039.	0.
Tamil Nadu	961.	1095.	749.	1.69	0.88	715.	254.
	(689.)	(230.)	(666.)	(1.39)	(0.99)	(705.)	(185.)
Tripura	686.	19.	685.	1.03	—	620.	17.
Uttar Pradesh	1008.	193.	985.	1.24	0.93	910.	131.
West Bengal	820.	161.	804.	1.25	1.00	742.	107.

Note: The data within parantheses have been computed excluding monazite areas
— Insufficient data for analysis.

Annual average : 790. ± 245. micro-Gy/year
State-wise Population weighted annual average : 688. ± 197. micro-Sv/year

Annual average : 752. ± 209. micro-Gy/year
State-wise Population weighted annual average : 686. ± 195. micro-Sv/year

(The last two averages have been computed excluding monazite areas)

TABLE 11. POPULATION-WEIGHTED AVERAGE AIR ABSORBED DOSE RATES REPORTED FOR VARIOUS COUNTRIES (BENINSON et al 1977)

Sr. No.	Country	Population-weighted Average air dose rate (terrestrial + cosmic) $\mu Gy\ y^{-1}$
1.	FRG	755
2.	GDR	1095
3.	Italy	930
4.	Japan	650
5.	Poland	780
6.	Switzerland	950
7.	India (This study)	750 ± 250

TABLE :12 THE AVERAGE RADIATION PER CAPUT FROM THE NATURAL BACKGROUND EXTERNAL RADIATION IN THREE DIFFERENT COUNTRIES

Country	Radiation per caput μSv/y	Reference
USA	540	Johnson et al 1981
UK	700	Hughes 1985
India	690 ± 200	This study

TABLE :13 DEATH RATES BY CAUSES IN INDIA (DINESH MOHAN 1982)

Cause	Annual mortality rate (per 100,000 population)
1. All causes	1400
2. Accidents (all types)	50
3. a) Cancer (all types)	43
b) Cancer (external natural background radiation-induced and assuming ICRP risk factor)	1 (estimated from present study)

FIG. 1a- THE ENVIRONMENTAL TLD

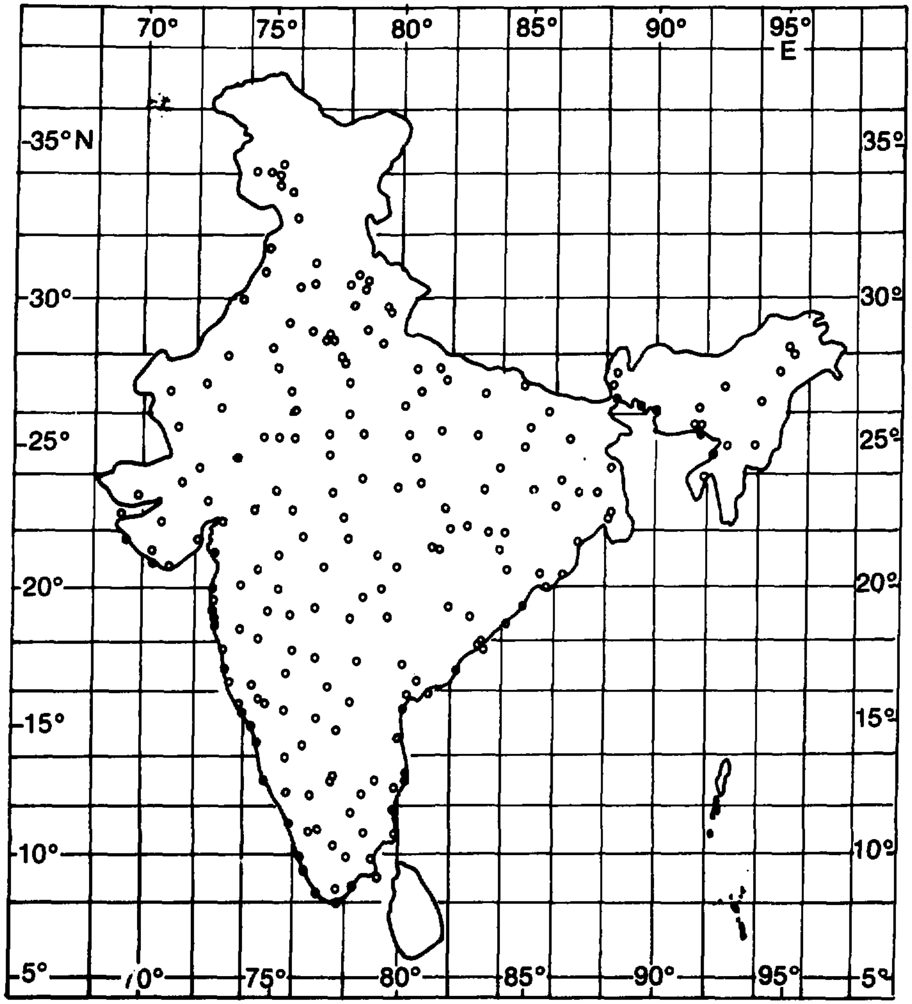

FIG. 1 ALL INDIA NATURAL BACKGROUND RADIATION SURVEY: TLD MONITORING STATIONS

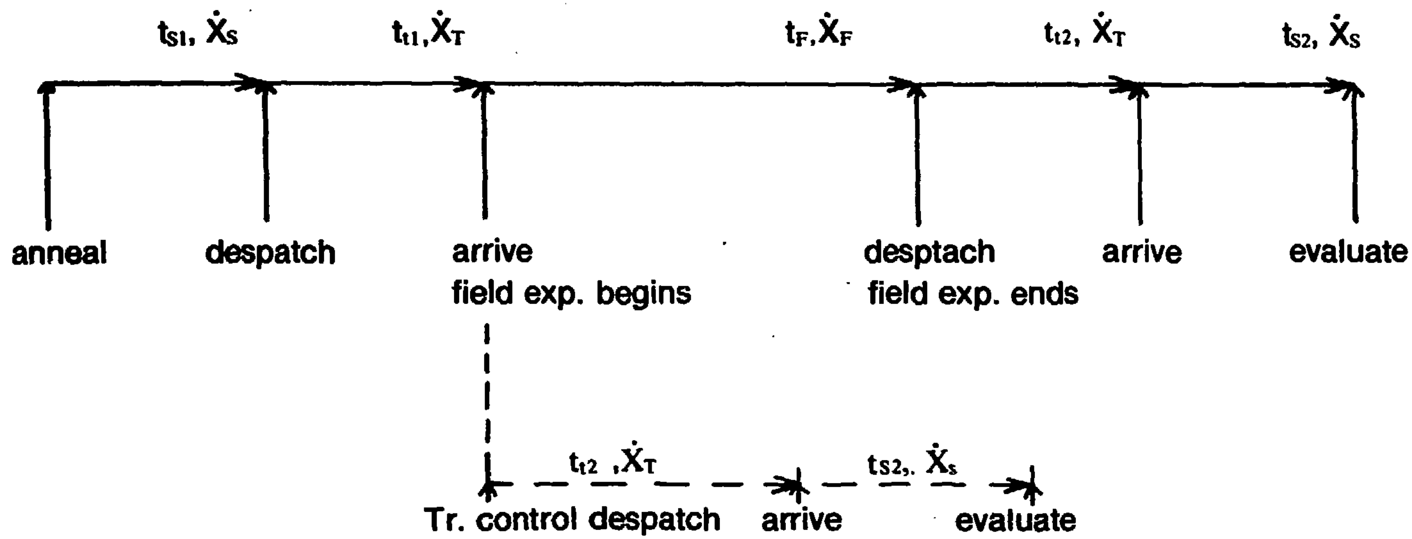

FIG. 2. IRRADIATION HISTORY OF FIELD AND TRANSIT CONTROL TLDs

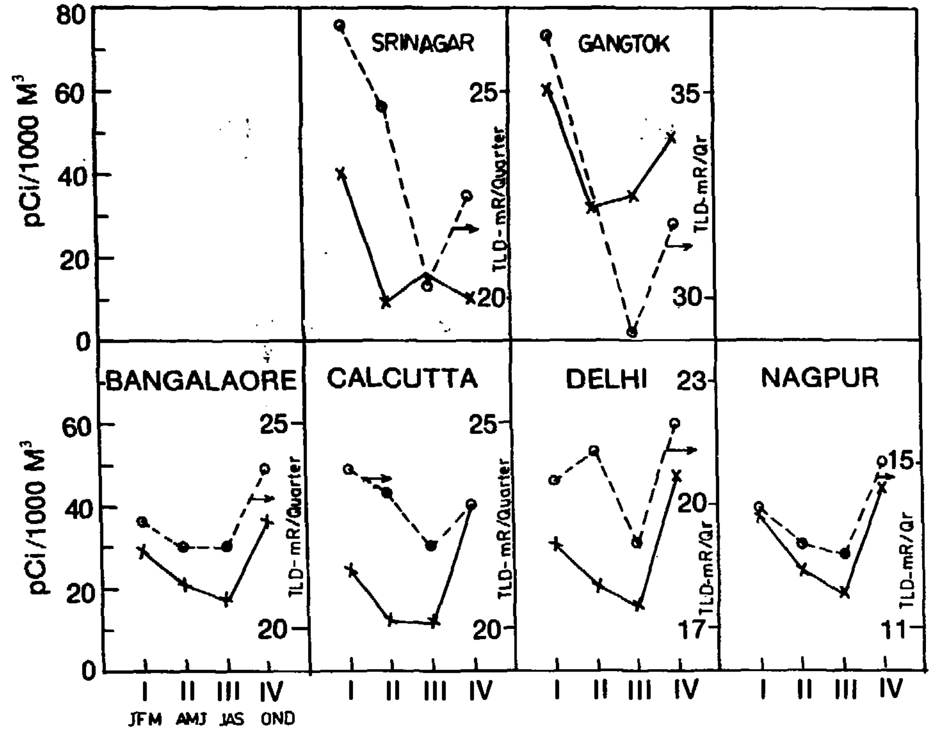

FIG. 3. QUARTERLY VARIATIONS IN RADON DAUGHTER AIR CONCENTRATIONS AND NATURAL BACKGROUND GAMMA RADIATION LEVELS (TLD VALUES) AT SIX LOCATIONS IN INDIA

——X—— Ra D (Pb 210) conc. in air averaged over the quarter

-- ⊖ -- TLD Values integrated over the quarter (1 mR = 8.7 μGy)

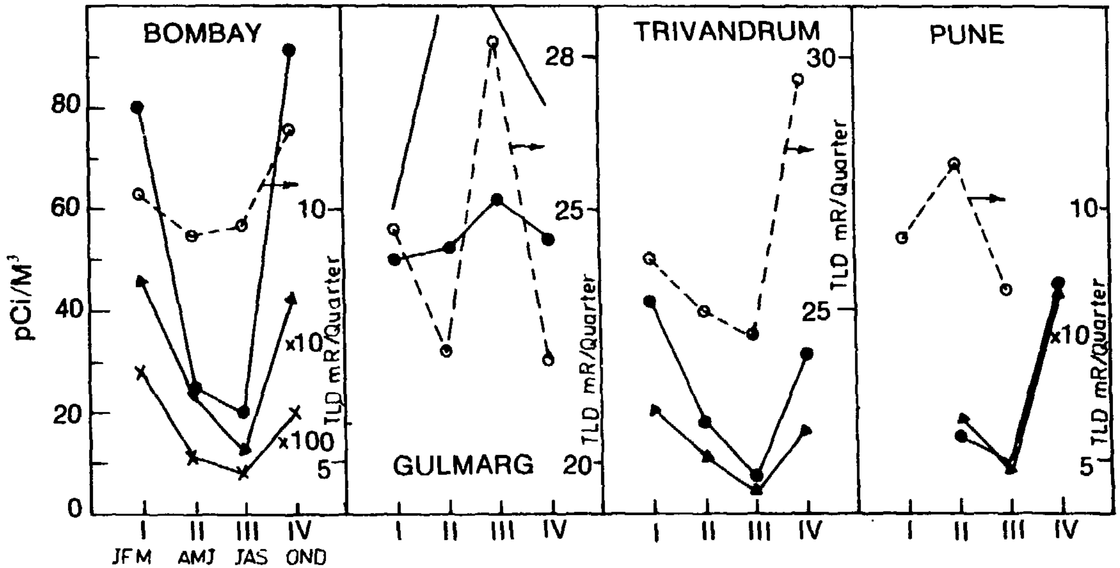

FIG. 4. QUARTERLY VARIATIONS IN RADON DAUGHTER AIR CONCENTRATIONS AND NATURAL BACKGROUND GAMMA RADIATION LEVELS (TLD VALUES) AT FOUR CITIES IN INDIA

—●— Ra—B (Pb—214) } Air conc. averaged over the quarter
—▲— Th—B (Pb—212)
—×— Ra—D (Pb—210)
- -o- - TLD Values integrated over the quarter (1 mR = 8.7 μGy)

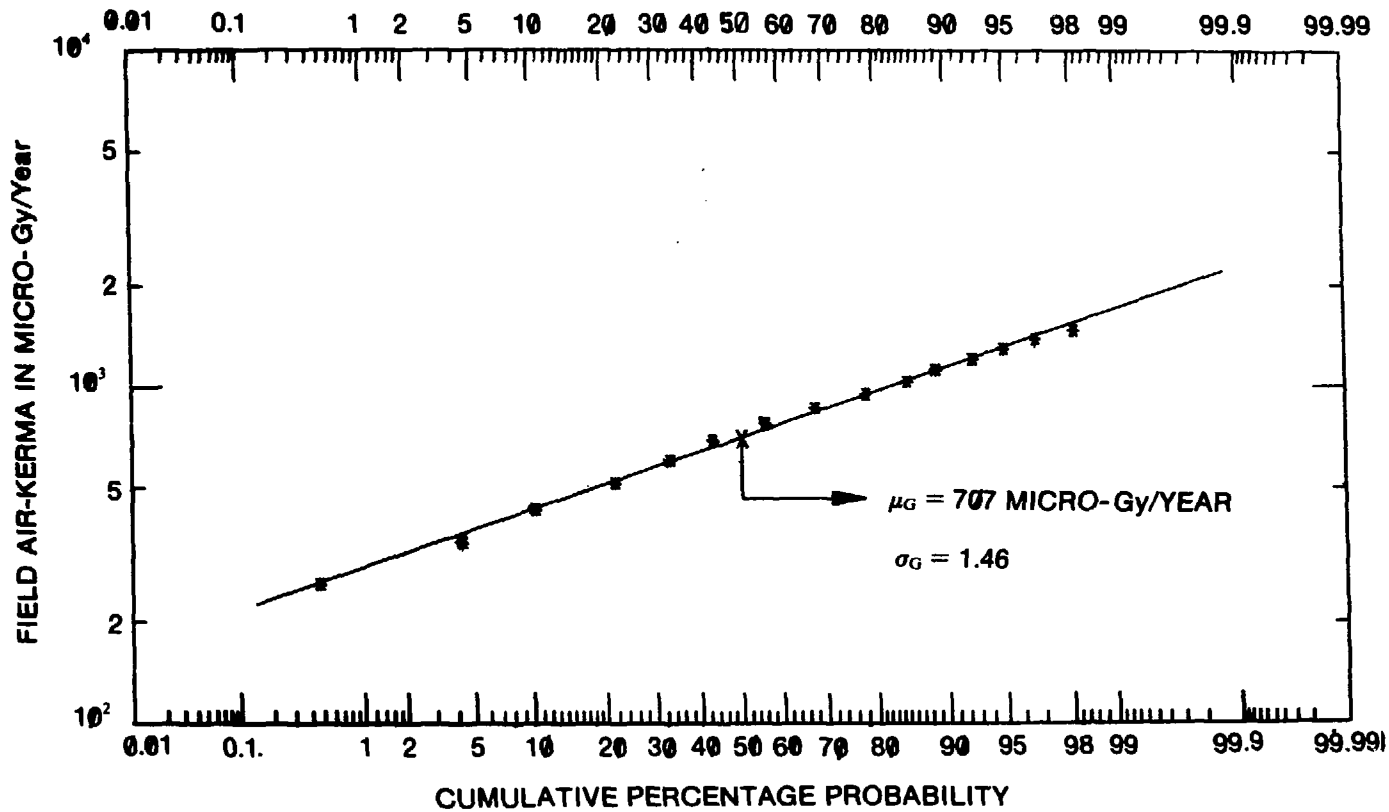

FIG. 5. ALL INDIA NATURAL BACKGROUND RADIATION LEVELS : RELATIVE CUMULATIVE FREQUENCY VS.ANNUAL AIR-KERMA VALUES

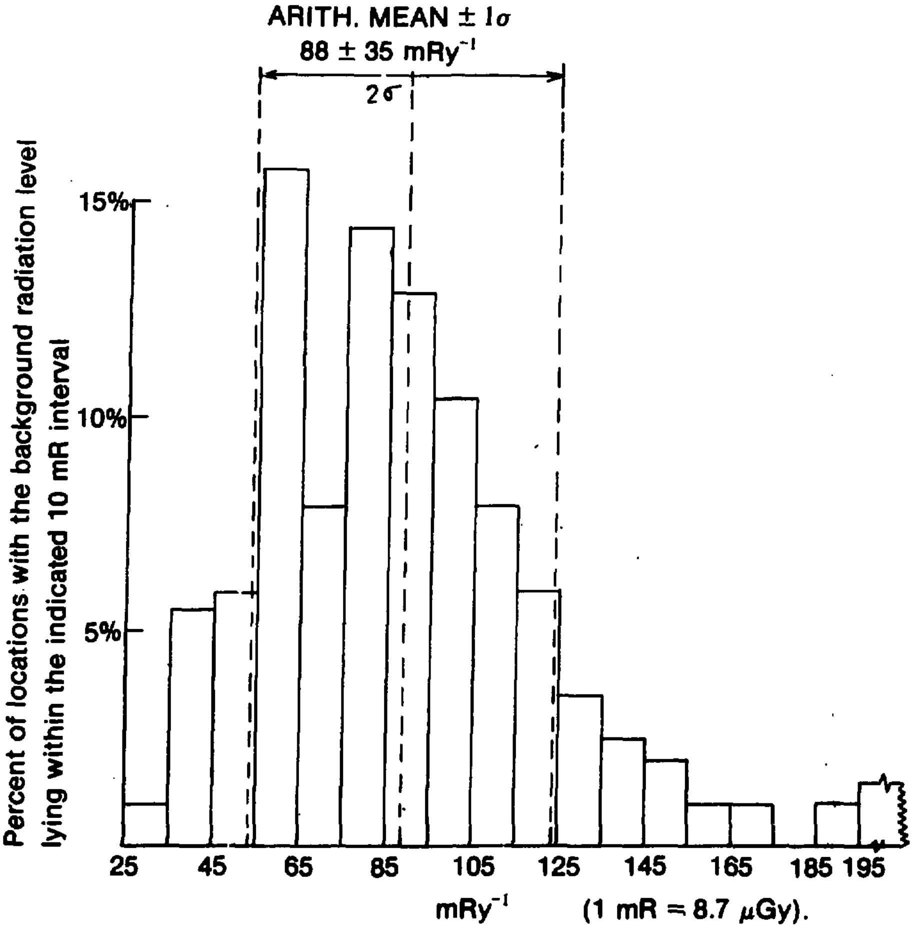

FIG. 6. NATURAL BACKGROUND RADIATION DISTRIBUTION IN INDIA

Number of locations monitored: 214

Period of monitoring: one year on quarterly cycles

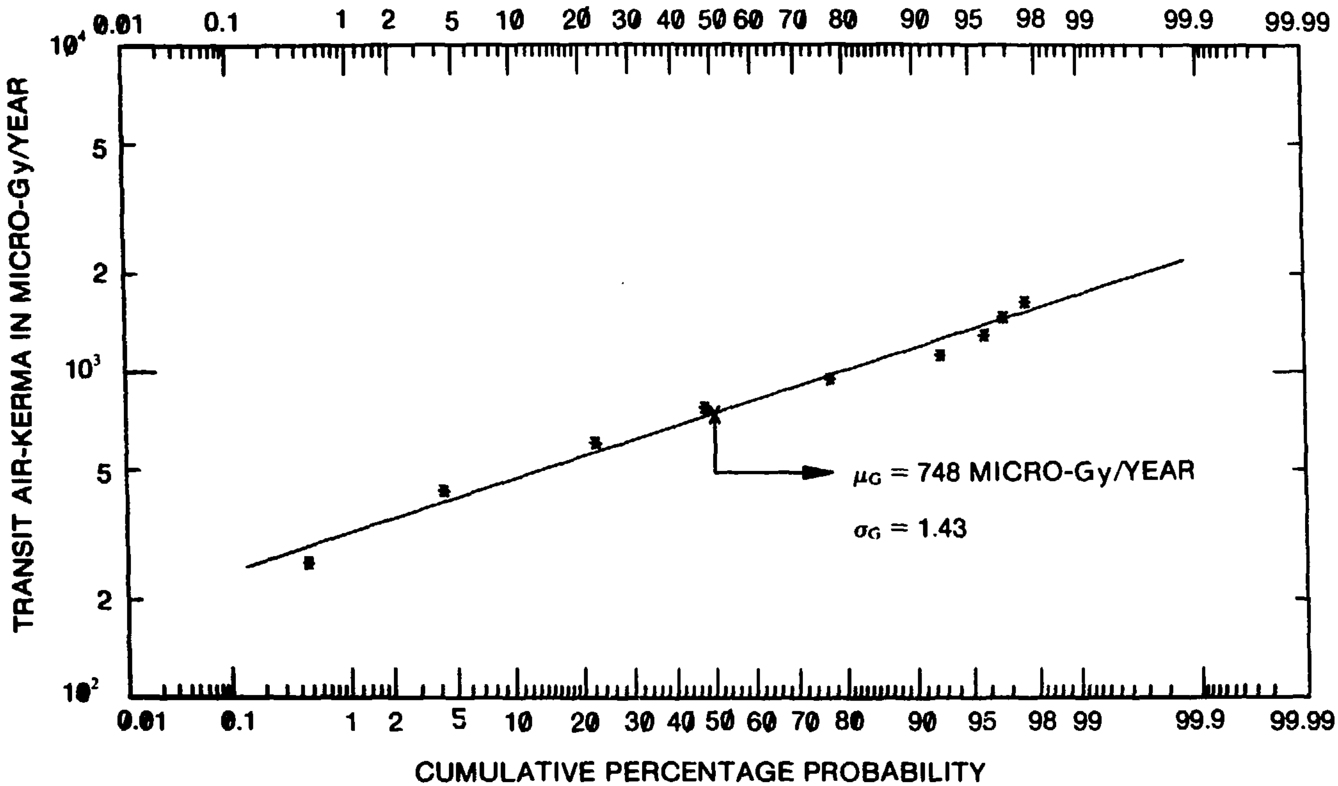

FIG. 7. ALL INDIA NATURAL BACKGROUND RADIATION LEVELS : LOGNORMAL DISTRIBUTION OF AIR-KERMA RATES EXPERIENCED BY TLDs DURING MAIL-TRAVEL

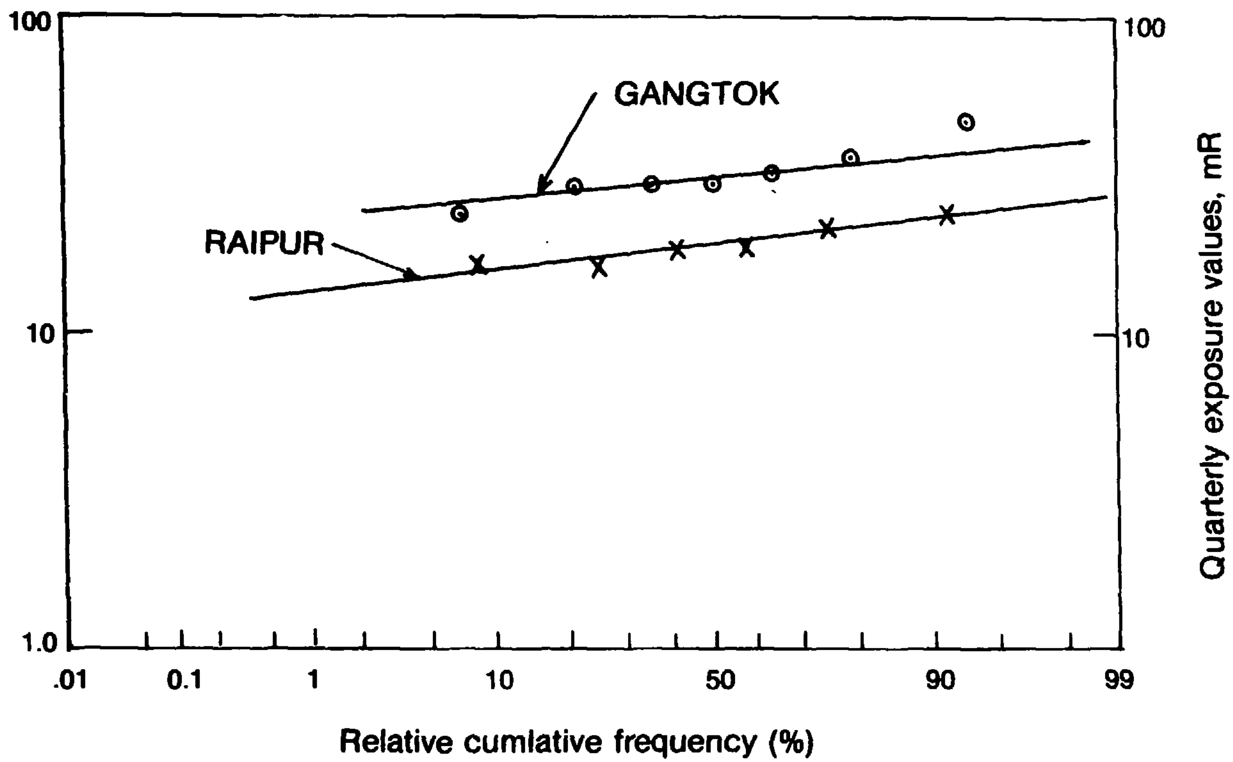

FIG. 8. LOG PROBABILITY PLOTS OF QUARTERLY BACKGROUND RADIATION LEVELS AT RAIPUR AND GANGTOK

(Period of monitoring: 6 & 7 consecutive quarters respectively)

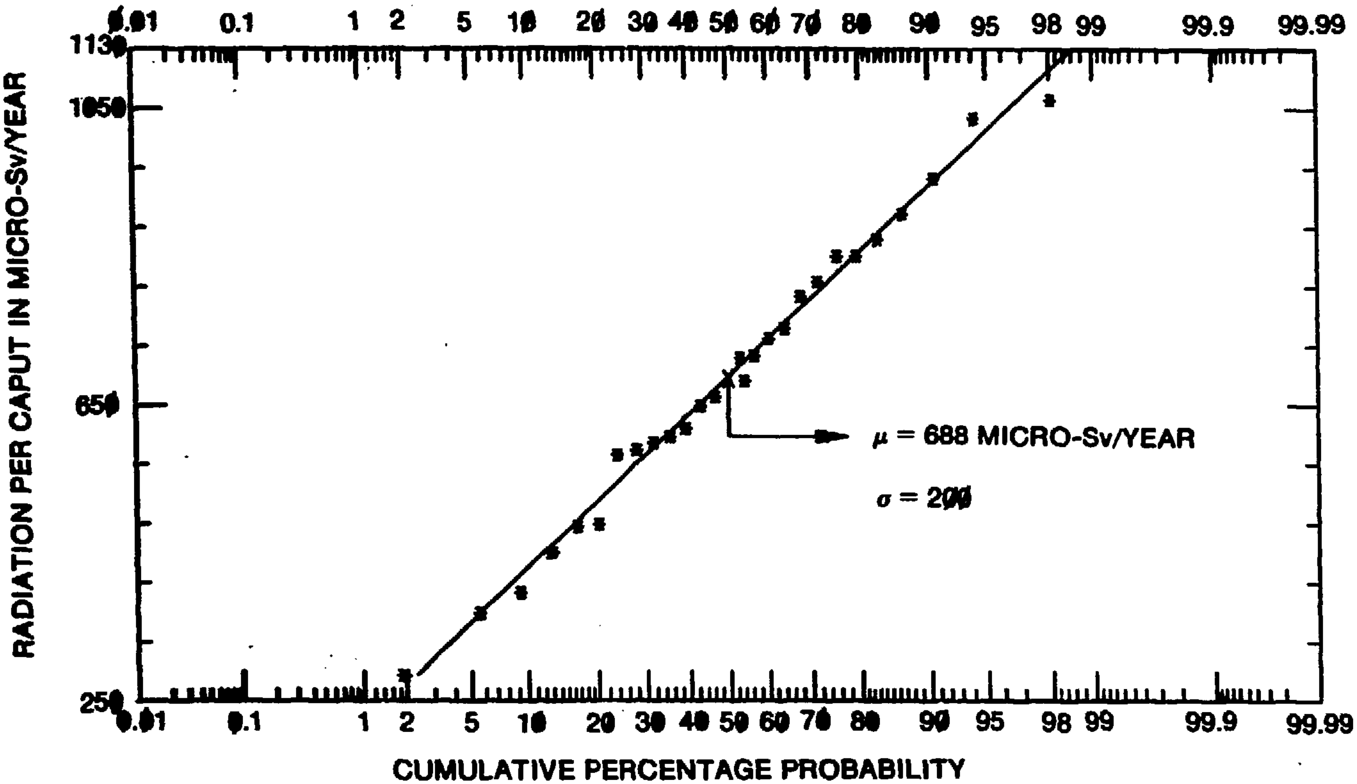

FIG. 9. THE NORMAL DISTRIBUTION OF POPULATION WEIGHTED STATE AVERAGE RADIATION PER CAPUT VALUES