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EVALUATION OF THE LONG-TERM EFFECTS OF HIGH BACKGROUND RADIATION ON SELECTED POPULATION GROUPS ON THE KERALA COAST*

A.R. GOPAL-AYENGAR, K. SUNDARAM, K.B. MISTRY, C.M. SUNTA, K.S.V. NAMBI, S.P. KATHURIA, A.S. BASU, M. DAVID
Bio-medical Group and Health Physics Division,
Bhabha Atomic Research Centre,
Trombay, Bombay, India

Abstract–Résumé–Аннотация–Resumen

EVALUATION OF THE LONG-TERM EFFECTS OF HIGH BACKGROUND RADIATION ON SELECTED POPULATION GROUPS ON THE KERALA COAST.

Investigations on human populations which are subjected to high levels of natural background radiation offer possibilities for evaluating the long-term effects of chronic radiation exposure in man. Monazite-bearing high-radiation areas exist along the south-west coast of India. Here a strip of about 55 km has definable geographical landmarks, includes the most concentrated distribution of monazite and supports a high density of population. Demographic data, including detailed fertility history for 13 355 households (about 70 000 individuals) of this strip were collected. Dosimetric survey of 20% of this population using calcium fluoride thermoluminescent dosimeters was completed. Processing of a representative sample of the dosimetric data revealed that about 20 000 individuals in this strip are likely to be receiving radiation dose between 5 to 10 times normal background. These data are being analysed to yield information on: (i) classification of population into sub-samples according to radiation exposure; (ii) sex-ratio among offsprings in each sub-sample; (iii) ratio of abortions and still-births to total pregnancies; (iv) ratio of congenital abnormalities to total live-births; and (v) infant mortality rates in each sub-sample. Studies of chromosomal patterns in new borns in this population and interlinking with radiation exposure history of parents have been initiated.

EVALUATION DES EFFETS A LONG TERME D'UNE HAUTE RADIOACTIVITE NATURELLE SUR DES GROUPES SELECTIONNES DE LA POPULATION DES COTES DE KERALA.

Une enquête sur les populations qui sont exposées à une haute radioactivité naturelle permet d'évaluer les effets à long terme de l'exposition chronique aux rayonnements chez l'homme. On trouve des régions à haute radioactivité naturelle, due à la présence de monazite, sur la côte sud-ouest de l'Inde. Une bande d'environ 55 kilomètres, géographiquement bien délimitée et à forte densité de population, a les concentrations les plus élevées en monazite. Les données démographiques, comprenant des détails sur la fécondité de 13 355 familles (environ 70 000 personnes) de cette région, ont été recueillies. L'étude dosimétrique de 20% de cette population a été effectuée à l'aide de dosimètres thermoluminescents au fluorure de calcium. Le traitement d'un échantillon représentatif des résultats dosimétriques a montré qu'environ 20 000 individus de cette région sont exposés à des doses de 5 à 10 fois supérieures au rayonnement naturel normal. On analyse ces renseignements en vue d'établir: i) la classification de la population en sous-échantillons selon la radioexposition; ii) la proportion des sexes dans la progéniture pour chaque sous-échantillon; iii) la proportion des avortements et des mort-nés en fin de grossesse; iv) la proportion des difformités congénitales pour la totalité des enfants nés vivants; v) les taux de mortalité infantile dans chaque sous-échantillon. On a commencé des études sur les types chromosomiques parmi les nouveau-nés de cette population et sur l'influence des antécédents de radioexposition des parents.

* This work has been supported in part by WHO under an Agreement dated 23 Dec. 1965.

ОЦЕНКА ДЛИТЕЛЬНОГО ВОЗДЕЙСТВИЯ ВЫСОКОГО ФОНОВОГО ИЗЛУЧЕНИЯ НА ОТДЕЛЬНЫЕ ГРУППЫ НАСЕЛЕНИЯ ПОБЕРЕЖЬЯ КЕРАЛА.

Исследования популяций человека, подвергающихся воздействию высокого фонового природного излучения, открывают возможности для оценки длительного влияния облучения на человека. Вдоль юго-западного побережья Индии расположены залежи монацита высокой активности. Полоса, длиной около 55 км, имеет наиболее концентрированные месторождения монацита и высокую плотность населения. В этом районе были собраны демографические данные, включая подробные данные о рождаемости, у 13 355 семей (примерно 70 000 индивидуумов). Было проведено дозиметрическое обследование 20% населения с помощью термолюминисцентных фтористо-кальциевых дозиметров. Обработка большого количества дозиметрических данных показала, что 20 000 индивидуумов в данном районе, по всей вероятности, получили дозу облучения, в 5-10 раз превышающую обычный фон. Эти данные анализируются, чтобы получить информацию по следующим пунктам: i) классификация населения на подгруппы по дозе облучения; ii) соотношение полов среди потомков каждой подгруппы; iii) отношение выкидышей и мертворожденных детей к общему количеству беременностей; iv) отношение врожденных аномалий к общему числу нормально рожденных детей; v) процент смертности детей в каждой подгруппе. Были начаты исследования хромосомных моделей новорожденных этой популяции и их взаимосвязи с историей облучения родителей.

EVALUACION DE LOS EFECTOS A LARGO PLAZO DE FONDOS RADIACTIVOS CONSIDERABLES EN LA COSTA DE KERALA SOBRE GRUPOS SELECCIONADOS DE POBLACION.

Las investigaciones sobre las poblaciones humanas que están sometidas a fondos radiactivos naturales elevados ofrecen la posibilidad de evaluar los efectos a largo plazo de la exposición crónica a la radiación en el hombre. A lo largo de la costa sudoccidental de la India existen zonas de radiación elevada, por su contenido en monacitas. En este lugar, una franja de unos 55 km con límites geográficos definidos, presenta la mayor concentración de monacitas y tiene una gran densidad de población. Se han recogido datos demográficos, un historial detallado de la fertilidad en más de 13 355 círculos familiares (unos 70 000 individuos) de esta franja. Se ha finalizado un estudio dosimétrico del 20% de esta población utilizando dosímetros termoluminiscentes del fluoruro cálcico. La elaboración de los datos dosimétricos de una muestra representativa reveló que unos 20 000 individuos de esta franja está recibiendo muy probablemente dosis de radiación comprendidas entre 5 y 10 veces el fondo normal. Estos datos se están analizando para obtener información sobre: 1) la clasificación de la población en muestras estratificadas de acuerdo con la exposición a la radiación; 2) la relación de sexo en la descendencia de cada estrato muestral; 3) la relación de abortos y nacidos muertos a embarazos totales; 4) la relación de anormalidades congénitas al total de nacidos vivos, y 5) las tasas de mortalidad infantil en cada estrato muestra. Se han iniciado estudios de los modelos cromosómicos en los recién nacidos de esta población y su conexión con el historial de exposición a la irradiación de los padres.

1. INTRODUCTION

Ever since the demonstration that ionizing radiations are mutagenic in lower forms of life, there has been an increased tendency on the one hand to regard all unwanted exposures to these radiations as harmful and on the other to identify areas where human populations are subjected to high levels of natural background radiations. It has been the fervent hope that investigations on such populations may perhaps lend themselves to critical analysis and thus provide more meaningful answers to yet unresolved questions: Do chronic exposures of human populations indeed result in genetic harm? And are estimates of risk based on animal experiments indeed valid for the human situation? The task we have set ourselves is complex and direct answers to these questions are unlikely to emerge in view of the many imponderable variables in the nature and styles of life of the populations studied.

One such geographical area, where large human populations are involved, lies along the west coastal region of Kerala and Tamil Nadu (Fig. 1).

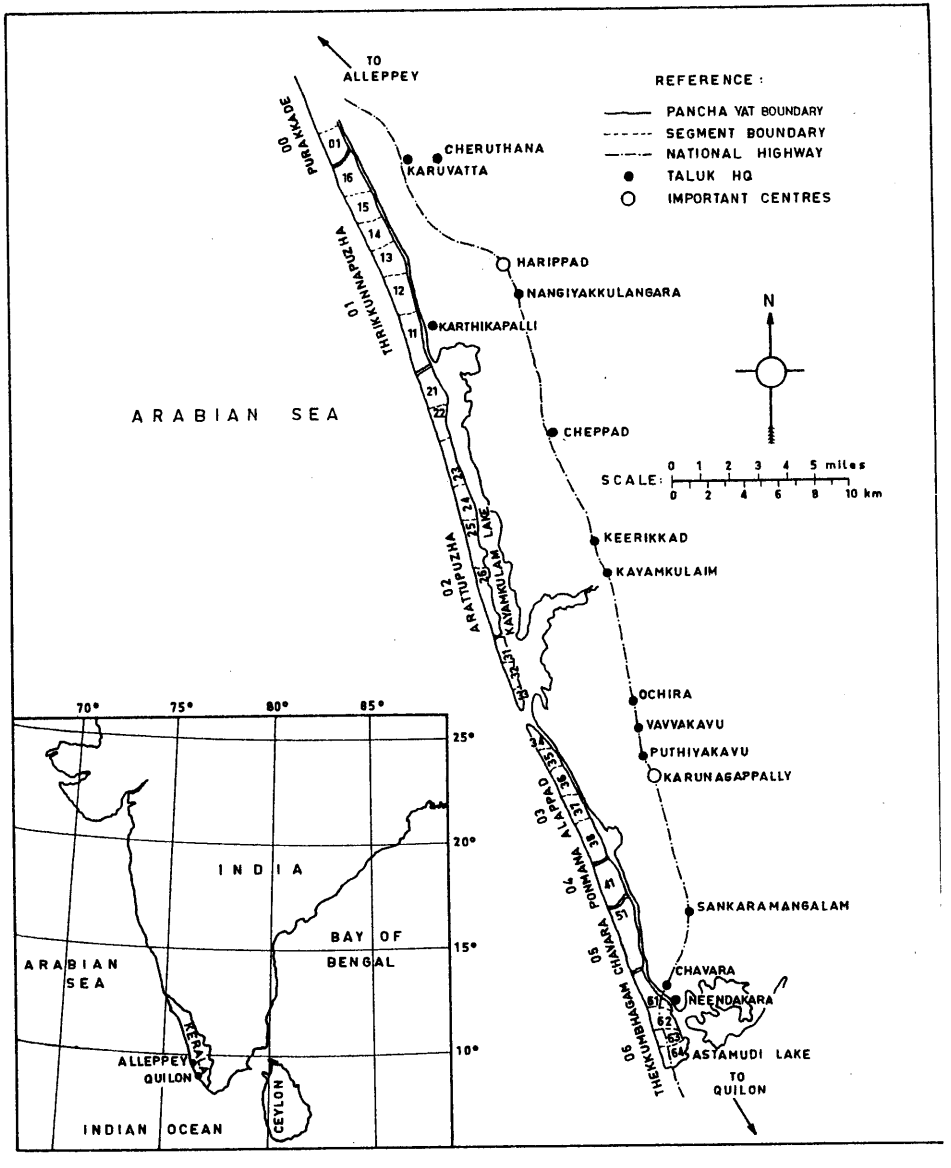

FIG. 1. Monazite bearing area surveyed in Kerala.

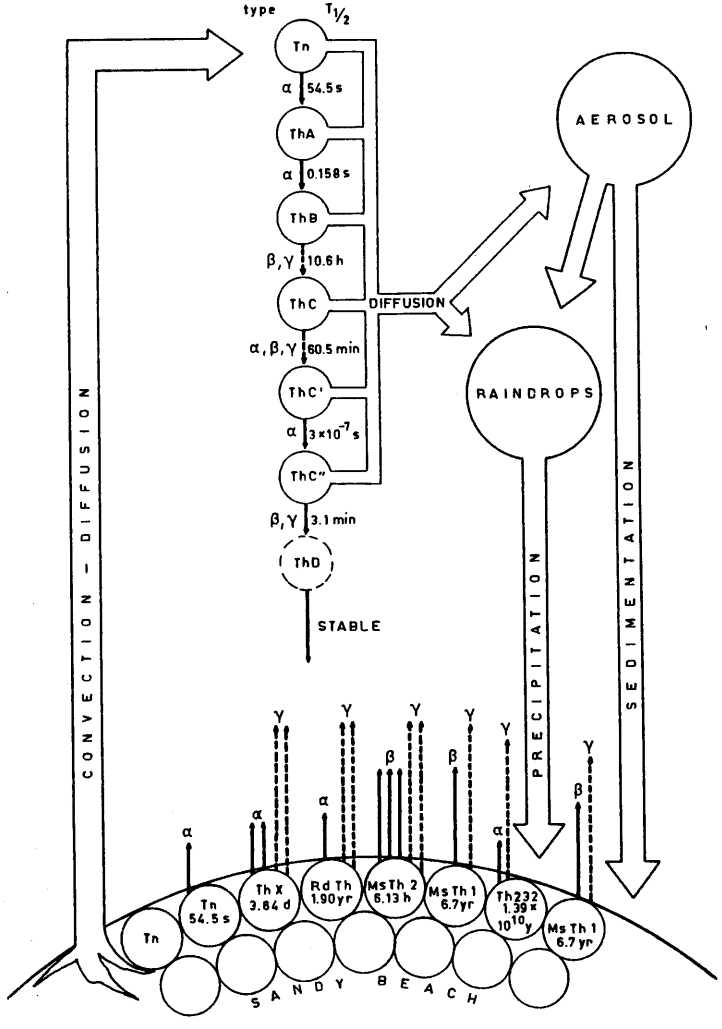

FIG.2. Schematic representation of the decay chain of thorium and its daughter products.

Here over a stretch of about 160 kilometres the coastline is characterized by patches of radioactive sand. For the purposes of our investigations we have selected a coastal strip of about 55 km extending from Thekkumbhagum in Quilon District in the south to Purakkadu in Alleppy District in the north. This area has certain features: (i) the area includes the most concentrated distribution of monazite; (ii) it has definable geographical land marks with the backwaters separating this strip from the mainland; (iii) it carries a high density of population.

The monazite deposits admixed with ilmenite, rutile, zircon and other rare earths are widely distributed in the beach sands and in the adjoining areas along this coastal strip. Thorium and its radioactive decay products contribute to the high background radiations. Figure 2 presents a schematic representation of the decay chain of thorium and its daughter products. It is evident that during the decay of thorium, alpha, beta and gamma radiations are released – as is also radioactive thoron, which diffuses out of the sands and contributes to the contamination of the air. Therefore, the human populations living in these areas are subjected to radiation exposures from: (i) external radiations caused by beta and gamma radiation from natural uranium and thorium contained in monazite; (ii) beta and gamma radiations from radon, thoron (gaseous products) and their decay products in the air; and (iii) internal exposures from deposition of these radioactive materials in the body through ingestion and inhalation.

This paper reports on the present status of our studies in the region. During the current phase of the project, two aspects have been taken up:

(a) An ad hoc demographic survey;
(b) Radiation dosimetric measurements of households and personnel.

A preliminary progress report on these investigations was published during 1970 [1]. The data reported therein which pertain to a small sub-sample of the households and population in the monazite belt, are incorporated in the present paper.

2. MATERIALS AND METHODS

2.1. Demographic survey

The demographic survey was completed in January 1970 with the assistance of the Bureau of Economics and Statistics, Kerala State. The region under study is divided into 7 areas and each area is subdivided into segments, and each house in a segment is given an individual house number. In all 13 355 households are included in the region and nearly 70 000 persons representing all age groups and different religions are covered. A batch of investigators visited each household and the demographic data were collected in computer-compatible formats [2]. The population has been divided into three occupational groups representing: (I) individuals employed outside the area; (II) individuals totally employed within the area; and (III) fishermen. The occupational Group I includes children going to school and other individuals who spend a good part of the day outside the area, but does not include fishermen. Occupational Group II includes male members who normally work in the area, housewives, and children who do not go to school but spend the day in and around the house. Occupational Group III consists of all persons who go fishing and spend the rest of their time in and around the area. This classification is important since human beings are mobile and the fact that they are resident in a high background area may not necessarily imply that they always receive high exposures. For each married couple in a household, a detailed fertility history has also been obtained.

A preliminary inquiry in the region revealed that there are various religious groups clustered discretely along the coast and it was difficult to get a suitable control population which would meet all requirements outside the region. Further, information obtained from our earlier radiometric surveys [3-6] indicated that along the coast the high radiation belt is frequently interrupted by stretches with normal background radiation levels. In view of this unique situation, it was felt that a sizeable fraction of the population would be receiving low or near normal background levels of radiation exposure which could justify this fraction being considered as a suitable control group.

2.2. Dosimetric survey

Our earlier radiometric surveys have demonstrated the patchy distribution of monazite sand in the Thekkumbhagum to Purakkadu region. In addition, the radioactivity in a given zone is relatively high near the shoreline and generally falls off as one moves inland by about 400 m [5]. These measurements were made by the conventional G-M survey meters. In the absence of reliable personnel integrating dosimeters, no measurements on individuals residing in the area could be carried out earlier. These studies however highlighted the complexity of the situation and also indicated that the computation of per capita annual dose on the basis of a single G-M measurement was likely to overestimate the actual doses received by the individuals in the population.

2.2.1. Dosimetric system

The development of thermoluminescent dosimeters, and especially calcium fluoride dosimeters at the Bhabha Atomic Research Centre, has now made it possible to measure the radiation dose received by individual members of the population with a reasonable measure of accuracy, reliability and reproducibility.

Dosimeter design and reader system have been reported earlier [7-9]. The dosimeter consists of a 40 mm × 12.5 mm × 0.25 mm Al variety kanthal strip at the centre of which fluorite TLD powder (50 to 100 mg, mesh 120) is deposited and secured by a silicone resin. For reading the light output from an exposed dosimeter, an EMI type 9514S photomultiplier tube is used, whose output is recorded when the dosimeter is heated under its photocathode. Minor modifications were made on this dosimeter for its use in the present work: A 15 mm × 10 mm × 0.5 mm depression was embossed at the centre of the kanthal strip, ensuring firm deposition of the fluorite. The kanthal strip dosimeter was enclosed in a light-tight black PVC bag which was in turn finally sealed inside another PVC packet.

Figure 3 shows the dosimeter which was supplied to the individuals. Female members of the population wore these dosimeters around the neck, children and male members wore them around their waist. The effect of variations in the geometry of these dosimeters on the exposure recorded was not significant.

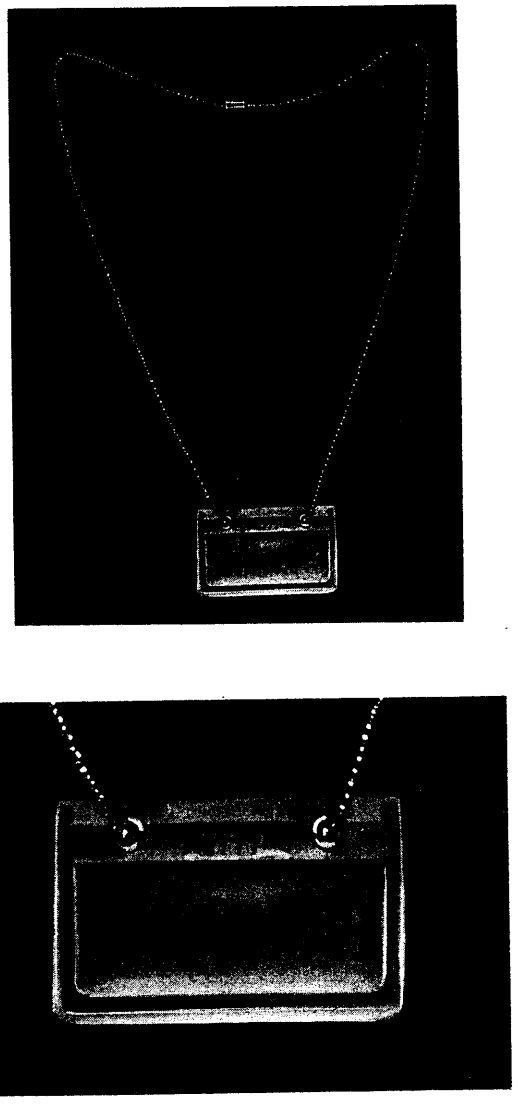

FIG.3. A typical CaF_2-TLD with chain.

2.2.2. Calibration procedure

Calibration of the dosimeters was carried out using a 9.14 mCi standard radium source enclosed in a 0.0625 in (1.588 mm) thick Perspex capsule. Dosimeters were arranged along the circumference of a 10 cm radius ring with the source at the centre. Twenty-eight dosimeters were placed in the calibrating ring at a time. Initially full range calibration was done for a few dosimeters and the range of linearity

was established. Linearity extends from 10 mR to 10^4 R [7]. There was no change in the calibration of the dosimeters, even after repeated use. In view of the large number of dosimeters used in this study, each dosimeter was calibrated at two exposure values, 20 mR and 100 mR, though even a single point calibration would have been adequate. A calibration line was drawn on a log-log graph with a slope of unity. If both the calibration points did not fall on the unity slope line, the calibration was repeated or the dosimeter rejected. In addition, 3% of dosimeters returned from the field were recalibrated and no change was detected in most batches.

An important factor affecting the calibration is the energy dependence of dosimeters. Calcium fluoride being of comparatively high effective atomic number has an energy dependent response [7, 8]. This problem has been overcome in the present work by using radium gammas for calibration. The comparative response values of CaF_2 TLD per roentgen of exposure from the radium source was found to be very close to that from the gamma rays of the thorium series which predominate in the monazite belt. The weighted average of TLD response per roentgen was 1.42 for the radium source and 1.40 for the thorium series gamma rays.

2.2.3. Mode of dosimetric survey

About 20% of the households in each of the areas in the region were covered by the dosimetric survey. The selection of the households was made from the table of random numbers. In all 12 716 dosimeters were issued. Of these, 10 887 dosimeters were received back in good condition for reading. The remaining were either damaged or lost. The dosimeters were worn by the individuals throughout the day and night for a period of two months. One dosimeter was also placed at approximately 3 ft above ground level in each of the households surveyed. All dosimeters were run through the reading cycle just prior to despatch to the field in order to erase previously accumulated background exposure. A set of dosimeters from each batch was returned to the main laboratory at Bombay immediately on receipt in Kerala to correct for the exposure during transport by air. Another set of control dosimeters was maintained at the field headquarters of the project located at Trivandrum outside the monazite belt. At the end of two months, all dosimeters including the controls were collected and read. The household and personnel radiation exposures reported here were corrected for the exposure recorded by the control dosimeters during their transit from Bombay to Trivandrum and back.

2.3. Analysis of data

The dosimetric and demographic data have been analysed to yield the following information:

(a) Classification of the households and population into sub-samples according to the radiation environment and personal dose received;
(b) Fertility index;
(c) Sex ratio among the offspring in each of the sub-samples;
(d) Ratio of abortions and still-births to total pregnancy;
(e) Ratio of congenital abnormalities to total live births;
(f) Infant mortality rates in each of the sub-samples.

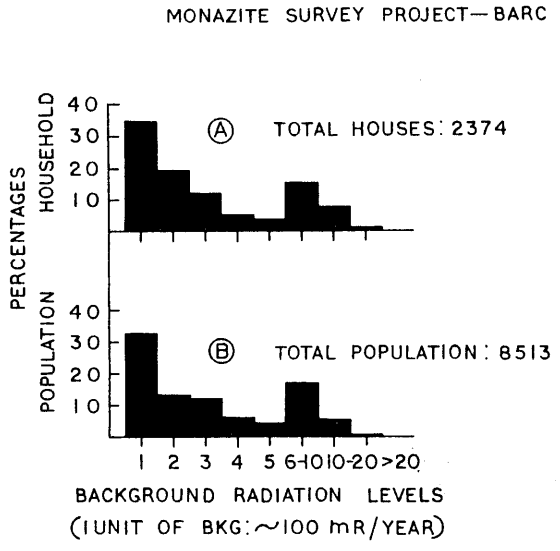

FIG.4. A. Household exposure distribution in all areas under survey;
B. Personal exposure distribution in all areas under survey.

3. RESULTS AND DISCUSSION

Data on the distribution of the 2374 households covered by the survey according to radiation exposure levels are presented in Fig. 4A. For the purpose of the present study, one unit of background radiation exposure level has been taken to be equal to 100mR/yr. This value is based on the exposures recorded in Bombay and Trivandrum which have normal natural background radioactivity.

It is evident from Fig. 4A that 24.6% of the households recorded levels greater than five times the normal natural background radiation level. 8.8% of the households received more than 10 times the normal radiation level, and 1.1% recorded more than 20 times the normal levels.

Details of the household exposure levels in each of the seven areas within the region under investigation are shown in Fig. 5. Data indicate that of the total households in each area those recording greater than 5 times normal natural background level constitute 49.9% and 80.3% in Thekkumbhagum and Chavara in the south, 16.8%, 26.5% and 1.2% in Ponmana, Allappadu and Arratupuzha in the middle of the coastal strip and none in Thirukkunnapuzha and Purakkadu in the north. Thus, as one proceeds from Purakkadu in the north to Thekkumbhagum in the south the fraction of households in each area receiving greater than 5 times normal background radiation exposure levels gradually increases with the maximum peak value in the Chavara area. Further, the percentages of households receiving greater than 10 and 20 times the normal levels are also observed to be highest in the Chavara and Thekkumbhagum areas.

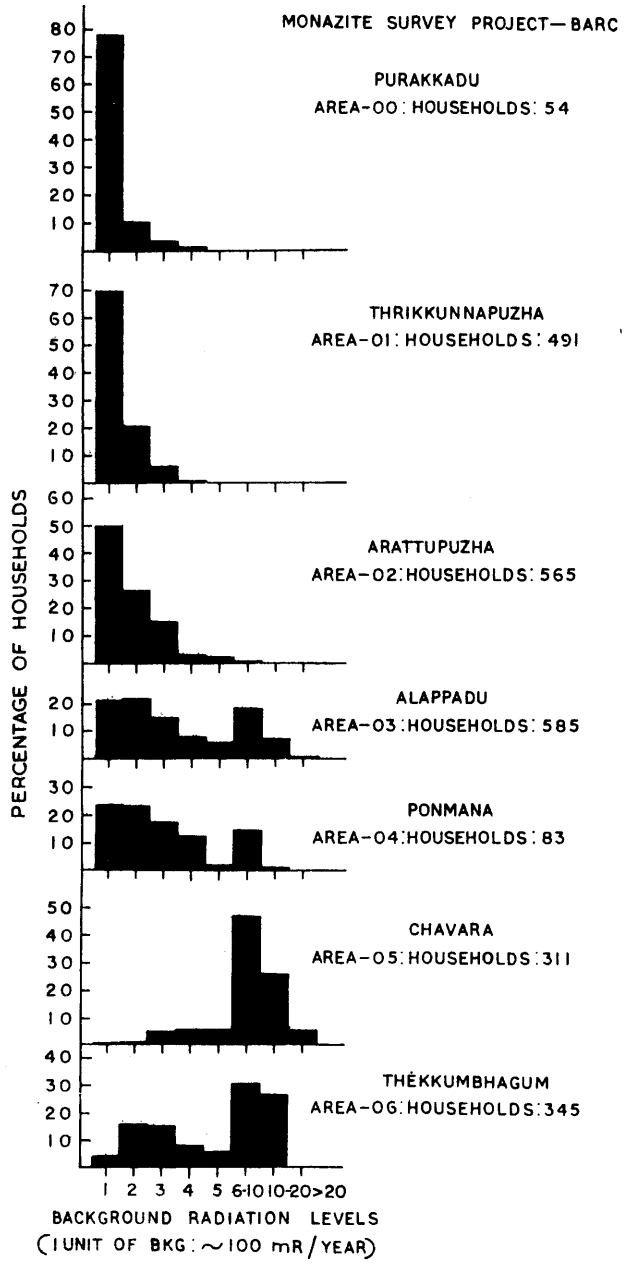

FIG. 5. Exposure distribution patterns in 7 different areas.

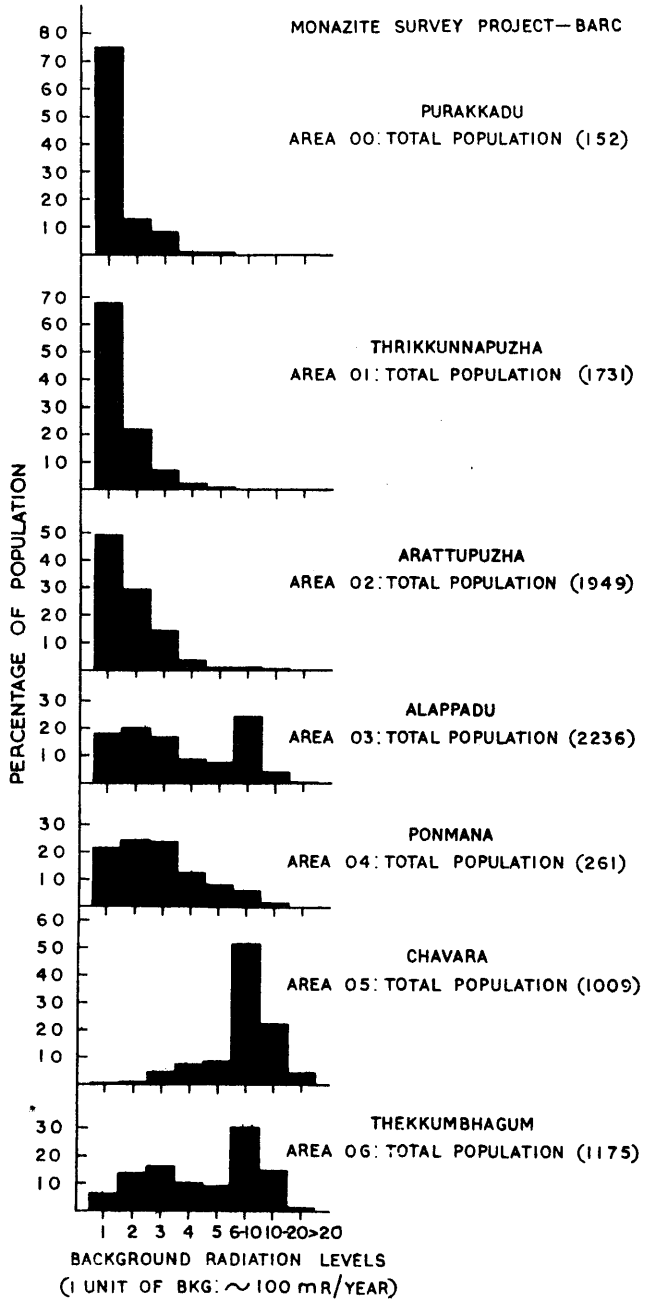

FIG. 6. Personal exposure data of all occupational groups included in the survey.

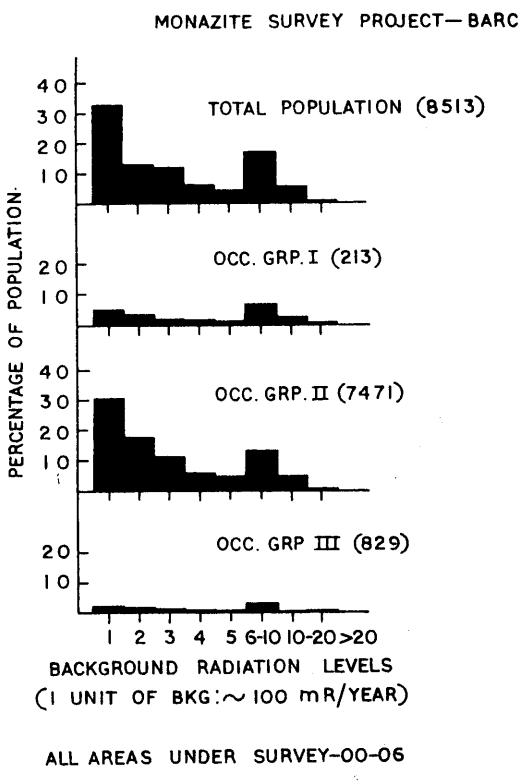

FIG. 7. Personal exposure patterns according to occupation.

We have also examined the individual household measurements in each of the seven areas; the exposure data reveal significant variations between adjacent households in a given area. This indicates that even in a specific area the distribution of monazite deposits is non-homogeneous.

Personal radiation exposure patterns of the total population of 8513 individuals included in the present study as well as the exposure pattern in each of the seven areas are shown in Figures 4B and 6, respectively. The exposure distribution profiles according to different occupational groups within the total population are presented in Fig. 7. Further, the areawise radiation exposure profiles for occupational Group II, which constitutes about 90% of the total population surveyed, have also been computed separately and are given in Fig. 8.

The main feature of personnel dosimetric results is that the radiation exposure profiles for the population taken as a whole (Fig. 4B) as well as in each of the seven areas (Fig. 6) reveal a close similarity to the household exposure profiles (Figs 4A and 5). Between different occupational groups, the exposure profile for Occupational Group II shows the closest fit with the total population profile (Fig. 7). Further, the areawise exposure distribution for individuals in Occupational Group II (Fig. 8), who are

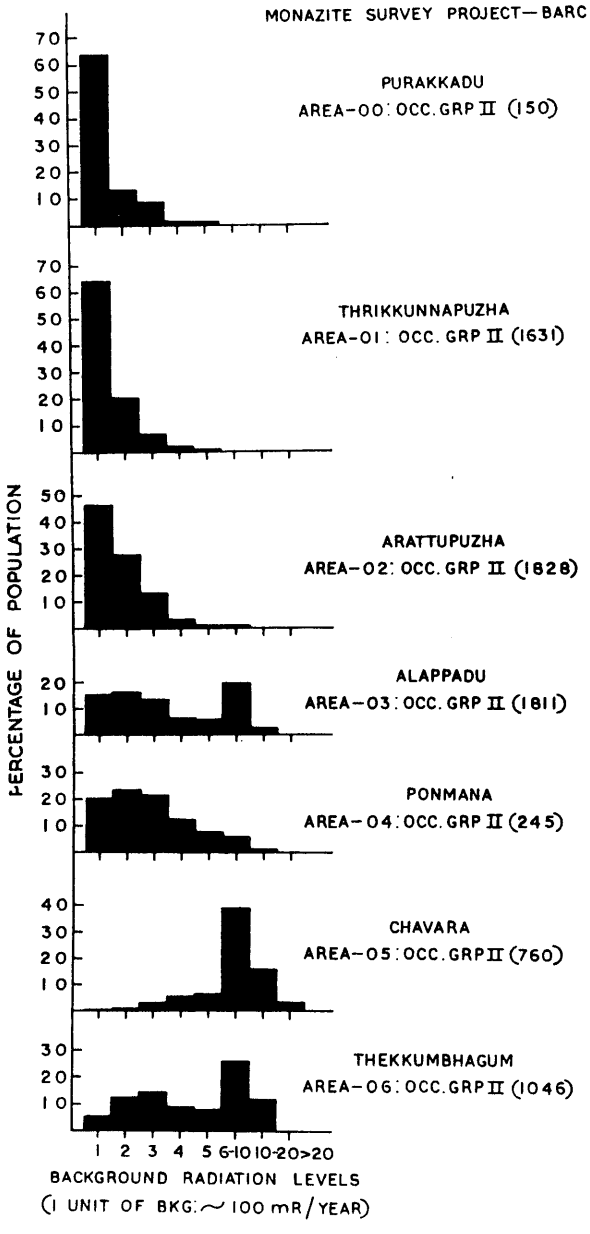

FIG. 8. Personal exposure data of Occupational Group II included in the survey according to the different areas of residence.

TABLE I. SUMMARY DATA ON FERTILITY AND PREGNANCIES OF MARRIED COUPLES RESIDENT IN MONAZITE BELT INCLUDED IN THE DOSIMETRIC SURVEY

BKG Levels	No. of couples	No. of living children			Children born alive, since dead			Children born alive	No. of still-births				Abortions and miscarriages	Total pregnancies	Twins	Gross abnormalities
		M	F	T	M	F	T		M	F	U	T				
1 to 5	1887	3955	3731	7686	1168	1098	2266	9952	219	127	38	384	503	10773	66	39
6 to 10	407	896	795	1691	202	196	398	2089	36	30	8	74	102	2244	21	12
11 to 20	104	218	249	467	51	47	98	565	1	7	2	10	20	589	6	3
> 20	22	46	36	82	9	13	22	104	3	3	1	7	4	114	1	-
Total	2420	5114	4811	9925	1430	1354	2784	12709	259	167	49	475	629	13 720	94	54

1 unit of BKG: ~100 mR/year.
M = male; F = female; U = sex unknown; T = total.

totally employed in the region, can be seen to mirror the areawise household radiation exposure profiles (Fig. 5). The latter observation lends a degree of confidence to the dosimetric data and the classification of the population according to occupation adopted in the demographic survey.

On the basis of the dosimetric data reported in the present paper, 2020 out of the 8513 individuals surveyed received exposures greater than 500 mR/yr. Of these, 551 individuals received exposures greater than 1R/yr while 57 individuals received a dose greater than 2R/yr. If these data are representative of the total population in the region, one could estimate that, as a first approximation, of the 70 000 individuals living in the region covered by the demographic survey about 16 600 are likely to be receiving a dose exceeding 500 mR/yr. This estimate would be the likely maximum value since, as discussed earlier, the individual household and hence the personnel exposure values between adjacent households in the same area show large variations chiefly due to the non-homogeneous distribution of the monazite deposits in the coastal belt. The per capita dose for the entire population resident in the region has been computed on the basis of the sample surveyed and it works out to 397 mR/yr.

3.1. Statistics of the population covered by the survey

Data on the pregnancies and their termination in the population covered by dosimetric measurements are presented in Table I. In addition, the raw data on the subsamples in each of the areas are also presented, in Table II. 2420 married couples with 13 720 pregnancies have been analysed. The couples are grouped according to the personal exposure received by the female member, since in general the maternal dose recorded was higher than the paternal dose.

Fertility index. The number of pregnancies per couple (Fertility Index) varied from 5.76 to 6.07. The differences between groups receiving different levels of background radiations are not statistically significant. The fertility indices of the subsamples are presented in Table III. It is observed that there is a tendency to lower values as one proceeds from Purakkadu in the north to Thekkumbhagum in the south. In addition, it is noticed that in two of the areas for groups where maternal radiation exposure levels are in excess of 20 background (BKG) units the fertility index of 4.99 is recorded, which is the lowest for the population surveyed. The number of couples falling in this group is only 22 and the data are not adequate for drawing definite conclusions.

Sex ratio among the off-spring. The sex-ratios of the offspring have been computed for three groups, living, still-born and infant mortality. The data are presented in Table IV. The values obtained for the various groups show wide variations and no clear cut patterns have emerged. On the basis of genetic considerations, maternal exposure would result in fewer males among the living offspring and a greater loss of males through still-births and early deaths during the first year after birth. Though the number of living male children in the group receiving 11 to 20 BKG units are significantly lower than in those groups receiving lower background levels of radiation, it is observed that the group receiving over 20 BKG units does not show this trend. In fact, there appears to be a small excess

TABLE II. PRIMARY DATA ON FERTILITY AND PREGNANCIES OF MARRIED COUPLES RESIDENT IN MONAZITE BELT INCLUDED IN THE DOSIMETRIC SURVEY

BKG levels	Area code	No. of couples	No. of living children			Children born alive, since dead			Children born alive	No. of still-births				Abortions and miscarriages	Total pregnancies	Twins	Gross abnormalities
			M	F	T	M	F	T		M	F	U	T				
1 to 5	00	75	172	186	358	59	51	110	468	5	3		8	30	505	1	
	01	535	1091	1028	2119	383	337	720	2839	58	23	7	88	163	3072	18	15
	02	542	1104	970	2074	342	318	660	2734	67	44	16	127	134	2978	17	9
	03	446	951	943	1894	250	274	524	2418	56	38	11	105	103	2608	18	7
	04	69	151	128	279	32	28	60	339	16	11	2	29	18	382	4	7
	05	55	123	108	231	28	23	51	282	1	3		4	17	299	4	1
	06	165	363	368	731	74	67	141	872	16	5	2	23	38	929	4	
6 to 10	00																
	01																
	02	8	20	15	35	5	3	8	43		1		1	2	46		
	03	143	324	277	601	78	72	150	751	11	11	2	24	30	797	8	7
	04	6	18	16	34	2	9	11	45	1			1	3	49		1
	05	133	292	249	541	63	65	128	669	15	12	4	31	32	726	6	4
	06	117	242	238	480	54	47	101	581	9	6	2	17	35	626	7	
11 to 20	00																
	01																
	02																
	03	21	48	47	95	7	8	15	110					4	114		1
	04	1	4	1	5	1		1	6						6		
	05	49	89	114	203	31	23	54	257	1	3		4	8	263	6	2
	06	33	77	87	164	12	16	28	192		4	2	6	8	206		
> 20	00																
	01																
	02																
	03	2	6	5	11		2	2	13	1			1	1	15		
	04																
	05	11	23	19	42	4	3	7	49	1	3	1	5	1	54	1	
	06	9	17	12	29	5	8	13	42	1			1	2	45		
Total		2420	5115	4811	9926	1430	1354	2784	12 710	259	167	49	475	629	13 720	94	54

1 unit of BKG: ~100 mR/year
00 - Purakkadu; 01 - Thrikkunnapuzha; 02 - Arattupuzha; 03 - Alappadu; 04 - Ponmana; 05 - Chavara; 06 - Thekkumbhagum
M = male; F = female; U = sex unknown; T = total

TABLE III. FERTILITY INDEX OF MARRIED COUPLES IN THE SAMPLED POPULATION

Area	Radiation exposure levels (BKG Units)[a]			
	1 - 5	6 - 10	11 - 20	> 20
0	6.7	-	-	-
1	5.74	-	-	-
2	5.49	5.75	-	-
3	5.85	5.57	5.43	7.5
4	5.54	8.1	6.00	-
5	5.43	5.45	5.40	4.99
6	5.63	5.35	6.24	5.0
Total ± S.E.	5.76 ± 0.16	6.04 ± 0.67	5.77 ± 0.15	5.83 ± 0.8

[a] BKG Unit: ~100 mR/year

TABLE IV. MALE: FEMALE SEX-RATIO AMONG THE OFFSPRING IN THE SAMPLED POPULATION

	Radiation exposure levels (BKG Units)[a]			
	1 - 5	6 - 10	11 - 20	> 20
Living	1.06	1.12	0.87	1.2
Stillborn	1.7	1.2	-	1
Infant mortality[b]	1.06	1.03	1.08	0.69

[a] BKG Unit: ~100 mR/year
[b] National average for rural India: 1.09 [10]

of males in this group as compared to others. Again the sex-ratio among the still-born shows a large excess of males among those couples receiving lower radiation exposures. The pattern of infant mortality also does not indicate any definitive trends and the figures for all groups except those falling above 20 BKG units are comparable to 1.09, a value computed from the data published by Registrar General, India [10] for infant mortality rates for rural India. The lower value observed in those couples receiving radiation exposures in excess of 20 BKG units may perhaps be explained as a compensatory phenomenon to off-set the reduced fertility index in this group, since surviving male children are regarded as potential wage earners to the family. The estimates of sex-ratio among the offspring have not provided any clue from which conclusions on the possibility of genetic damage to the population resident in the monazite bearing areas could be drawn.

TABLE V. INFANT MORTALITY RATE PER 1000 LIVE BIRTHS IN POPULATION

Area	Radiation exposure levels (BKG Units)[a]			
	1 - 5	6 - 10	11 - 20	> 20
0	235	-	-	-
1	253	-	-	-
2	241	186	-	-
3	216	199	136	153
4	171	244	166	-
5	180	191	210	143
6	162	174	146	309
Total ± S.E.[b]	208 ± 12.3	198 ± 9.7	164 ± 14.0	201 ± 52.4

[a] BKG Unit: ~100 mR/year
[b] National average for rural India: 145.9 [10]

Infant mortality rate. The data on the infant mortality rate are presented in Table V. It is observed that the values obtained are slightly in excess of 145.9, a figure estimated by the Indian National Survey for rural areas of India in 1963 [10]. A more recent estimate based on data of continuous enumeration on annual samples in 1968 gives an infant mortality rate of only 111 for the whole country. It is well known that infant mortality is one of the sensitive indicators of the living standards of a community and is particularly sensitive and responsive to improvements and deterioration in the environment in which the infant lives. The infant mortality rates computed from the data collected in our study gives a mean figure of 184. Such high values are recorded in other parts of India, notably in the state of Uttar Pradesh in northern India. Considering the primitive medical facilities available in the monazite bearing areas, inadequate sanitation and exposure to vagaries of nature, the high infant mortality rates seen in this population are not surprising. Again the differences in the infant mortality rates between the high and low background exposure levels are not statistically significant. However, it may be mentioned in passing that the highest value of 309 is recorded in the group of 9 couples living in Thekkumbhagum receiving an exposure greater than 20 BKG units, in whom 13 of the 42 children born died in the first year of their life.

Pregnancy terminations, abnormalities and multiple births. The data are presented in Table VI. It is observed that on an average 4.5% of pregnancies ended in abortions. The frequency of abortions in the four radiation exposure categories are not different. The frequency of still births in the group receiving a radiation exposure in excess of 20 BKG units is significantly higher than in other groups. As stated earlier, the infant mortality rate in this group was also the highest. It thus appears that the total loss of offspring in this group is significantly higher than in those

TABLE VI. PREGNANCY TERMINATIONS, ABNORMALITIES AND MULTIPLE BIRTHS IN THE SAMPLED POPULATION [a]

Parameter	Radiation exposure levels (BKG Units) [b]			
	1 - 5	6 - 10	11 - 20	> 20
Abortions (%)	4.66	4.54	3.40	3.50
Stillbirths (%)	3.60	3.30	1.70	6.14
Gross abnormalities (%)	0.36	0.53	0.50	-
Twins (%)	0.61	0.93	1.01	0.87

[a] As percent of total pregnancies
[b] BKG Unit: ~ 100 mR/year

receiving lower radiation exposures. It is proposed to study a larger group falling in this category in the near future. The frequency of gross abnormalities do not show any significant differences between the various groups.

4. SUMMARY AND CONCLUSIONS

In an attempt to evaluate possible genetic effects of chronic irradiation in man, demographic and radiation dosimetric surveys of the population resident in the monazite bearing high radiation areas of the Kerala coast in south-west India were undertaken. Demographic data including detailed fertility history of married couples of nearly 70 000 individuals resident in 13 355 households in a 55 kilometre strip along the monazite belt were recorded. Radiation exposure levels received by a randomly selected sample population of 8513 individuals resident in 2374 households in the coastal strip were also recorded, using calcium fluoride thermoluminescent dosimeters.

Dosimetric data revealed that about 25% of the households covered by the survey recorded greater than 5 times the normal natural background radiation level. The fraction of households receiving greater than 5 times the normal background exposure gradually increased from north to south along the strip. The percentage of households recording greater than 10 and 20 times the normal levels was also highest in the southern part of the strip.

The radiation exposure profiles for the population revealed a close similarity to the household exposure profiles. The profiles for individuals in Occupational Group II, who are totally employed in the region and which constitutes about 90% of the total population surveyed, was seen to mirror the household radiation exposure profiles. In all, 2020 out of the 8513 individuals surveyed received exposures greater than 5 times the normal levels (500 mR/yr). Of these, 551 individuals received exposures greater than 1 R/yr while 57 individuals received a dose greater than 2R/yr. On the basis of the data reported here, it can be estimated that of the

70 000 individuals living in the strip about 16 600 are likely to be receiving a dose exceeding 500 mR/yr. The per capita dose received by this population is estimated to be 397 mR/yr or nearly four times the normal background radiation level. Analysis of the demographic data indicated no statistically significant differences in fertility index, sex-ratio among offspring, infant mortality rate, pregnancy terminations, multiple births and gross abnormalities between population groups receiving different levels of radiation exposure. However, the lowest value of fertility index and the highest value of infant mortality rate were recorded for a group of married couples who received radiation exposures greater than 20 times normal background levels; the total loss of offspring in this group was significantly higher than in those receiving lower radiation exposures.

It is very likely that the various parameters which have been analysed in Phase I of this study are not sensitive enough to reveal any differences which are statistically significant. In view of the recent observations of radiation damage to chromosomes of human cells irradiated in vitro, it is hoped that human chromosomal studies of the population resident in the area would throw more light on the effects of chronic high background radiation on man. Phase II of the investigations would include, among others, detailed studies on blood lymphocytes from the new born, children of various age groups and adults on samples drawn from the various radiation exposure groups.

REFERENCES

[1] GOPAL-AYENGAR, A.R., SUNDARAM, K., MISTRY, K.B., SUNTA, C.M., DAVID, M., Paper presented to United Nations Scientific Committee on the Effects of Atomic Radiation, 20th Session, United Nations, Geneva (1970).
[2] Ad hoc Demographic Survey, Monazite Survey Project, Bio-Medical Group, Bhabha Atomic Research Centre, Trombay (1968).
[3] GOPAL-AYENGAR, A.R., in Effect of Radiation in Human Heredity, WHO Tech. Rep. Ser. No.166, World Health Organization, Geneva (1957) 115.
[4] BHARATWAL, D.S., VAZE, G.H., "Radiation dose measurements in the monazite areas of Kerala State in India", 2nd Int. Conf. peaceful Uses Atom. Energy (Proc. 2nd Conf. Geneva, 1958) 23, UN, New York (1958) 156.
[5] GOPAL-AYENGAR, A.R., MISTRY, K.B., "On the radioactivity of plants from the high radiation areas of the Kerala Coast and adjoining regions. I. Studies on the uptake of gamma-emitting radionuclides", Radioisotopes in Soil-Plant Nutrition Studies (Proc. Symp. Bombay, 1962), IAEA, Vienna (1962) 3.
[6] MISTRY, K.B., GOPAL-AYENGAR, A.R., BHARATHAN, K.G., Health Phys. 11 (1965) 1459.
[7] NAMBI, K.S.V., SUNTA, C.M., Ind. J. pure appl. Phys. 6 (1968) 294.
[8] NAMBI, K.S.V., SUNTA, C.M., Bhabha Atomic Research Centre, Trombay, Rep. BARC/HP/D-3 (1967).
[9] NAMBI, K.S.V., KATHURIA, S.P., SUNTA, C.M., "Radiation monitoring with a natural calcium fluoride thermoluminescent detector", Radiation Protection Monitoring (Proc. Regional Seminar Bombay, 1968), IAEA, Vienna (1969) 321.
[10] Sample Registration Bulletin No.20 (1968), Registrar General, India.