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Ernest O. Lawrence Radiation Laboratory

REPORT TO THE WORLD HEALTH ORGANIZATION ON A RADIATION SURVEY MADE IN EGYPT, INDIA, AND CEYLON IN JANUARY 1963

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ABSTRACT

A radiation survey has been made in three areas in AFRICA and southern ASIA using sodium iodide detectors, which were designed to eliminate to a large extent the effect of cosmic rays and to emphasize the γ rays of the natural environment. The first area chosen was in EGYPT, on the NILE DELTA near ROSETTA, where the survey was conducted from December 29, 1962 through January 1, 1963. A second survey was made in the states of KERALA and MADRAS in south INDIA, along the beach both north and south of the city of TRIVANDRUM, from January 10, 1963 through January 13, 1963. The third survey was carried out in south-western CEYLON, north and south of the city of COLOMBO, from January 15, 1963 through January 21, 1963.

This report deals only with the physical measurements made during these three surveys, and evaluates the dose levels that were instantaneously present in these areas. Such considerations as the fraction of the time the inhabitants spend in the areas where the radiation surveys were made and the interpretation of their biological condition together with any effects the radiation fields may have on the populace as a whole will be covered in another report. This report is confined to the measurement of γ rays in regions on the monazite beach deposits in these three areas.

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I. INTRODUCTION

A. Monazite

The three areas surveyed are wave-deposited beach sands of monazite that emit γ rays owing to their content of thorium. Monazite itself is a mixed phosphate of the cerium metals: cerium, lanthanum, and dysprosium. Small amounts of thorium oxide are possible spatial substitutions in the crystals for the cerium, in amounts varying between 1 and 10% thorium oxide. Monazite crystals are monoclinic and are generally a dull, opaque, reddish brown, although there are small translucent honey-colored crystals found in the ALPS. Some crystals coming from the URALS in NORWAY are as much as 5 in. on a side. The hardness of these crystals is about 5.5, and the density is between 5.1 and 5.2. The crystals are easily identified by their absorption spectrum.

Monazite is the cheapest and most plentiful thorium ore. The crystals are hard and resistant to weathering. The usual commercial crystals are between 0.1 and 0.2 mm in size and usually contain between 8 and 10% thorium oxide. Monazite is frequently separated out with ilmenite and zircon, both of which produce so-called "black sand." Thus monazite deposits often appear as black streaks on the beach. However, the dark color is due not to the monazite itself but to the accompanying ilmenite and rutile. A deposit containing only silica and monazite would probably not be identified by visual observation.

B. Distribution in the World

Commercial deposits of monazite crystals usually less than 1 mm in size are found in the beach sands of North Carolina, Brazil, Ceylon, southern India, and several other regions around the world. The monazite has been weathered from rocks (usually at some distance from the beach site), washed down by streams into the ocean, and then deposited on the beach, where it is separated by gravitational and hydraulic means from the lighter silicon sand.

The world's richest deposits of monazite occur in southern India in the state of Kerala. They are located at MANAVALAKURICHI in MADRAS as well as to the east of CAPE COMORIN at TINNEVELLY, and near WALTAIR and VISHAKAPATNAM. These deposits in India were discovered in 1909 and have been mined on and off ever since. A recent review article by F. L. Hess[1] also mentions that beaches similar to those in India and Ceylon exist on the northern coast of NEW SOUTH WALES and the southern coast of QUEENSLAND in AUSTRALIA.

The present low price of monazite restricts its mining anywhere except in India, where the deposits have the highest concentration of thorium. At various times in the past, successful mining has been carried out in Brazil and also in Ceylon and has been attempted in North Carolina. A considerable amount of mineral prospecting has been done, especially in the areas of southern India.

II. DESCRIPTION OF EQUIPMENT

A. Transistorized Rate Meter

One of the two instruments used in the field survey was designed and assembled at Lawrence Radiation Laboratory, and had been in use there since 1958. From 1958 to the beginning of this project (when the other instrument was built), a quarterly radiation survey was made in the vicinity of the SAN FRANCISCO BAY area, and this work has been partially reported in Health Physics, Vol. 4, No. 3 and 4, April 1961. The instruments have also been used in geologic investigations, and this work has been reported at the International Symposium on the Natural Radiation Environment held at Rice University, HOUSTON, TEXAS, April 10 through 13, 1963. Our experience has shown the instruments to be specific detectors of terrestrial γ radiation and to be reliable and rugged in field service.

The transistorized count-rate meter was designed by W. W. Goldsworthy

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[1] F. L. Hess, Industrial Minerals and Rocks (American Institute of Mining and Metallurgical Engineering, New York, 1949), pp. 523 to 526.

and is reported in Nucleonics 18, No. 1, pp. 92–99 (1960). His design has been slightly modified for our purposes but is basically the same. The instrument contains a Cockcroft-Walton high-voltage supply, a four-transistor linear pulse amplifier, a discriminator and differentiator to reduce low-frequency interference, and a rate-meter circuit. The electrical power for the instrument is supplied by a 10.75-V mercury battery, which provides 300 hours or more of operation. The count-rate meter has four linear ranges spanning an interval from 0 to 50,000 counts/sec, or in terms of our calibration, from 0 to 1.22 mR/hour. The high-voltage supply, discriminator, and amplifier all have potentiometer adjustments.

B. NaI Photomultiplier Assembly

The detector is a thallium-activated sodium iodide crystal 3 in. in diameter and 3 in. thick. The crystal is optically coupled to a Dumont 6363 multiplier phototube also 3 in. in diameter. The crystal and phototube assembly is surrounded with approx 1/2 in. foamed polystyrene or foamed rubber, or both, to guard against thermal and mechanical shock. Surrounding the assembly and its insulation is a 5-in.-diam by 12-in.-high stainless steel container, the side walls and bottom of which are 1/16 in. thick. According to Feather's rule, for stainless steel assumed to have a density of 7.85 g/cm^3, all β particles of less than 2.57 MeV will be excluded from the crystal. This estimate is conservative because the crystal is also canned in copper and surrounded by the insulation. The large size of the crystal makes it sensitive enough to always provide a count rate that is not influenced by statistical fluctuations, and reproducible readings are quick to make. The exclusion of β particles makes it possible to correlate field readings with laboratory pulse-height analysis of field samples, without being influenced by a changing β-γ ratio caused by changes in the field environment.

C. Calibration of Detector, Conversion of counts/sec to r/yr

The detector and rate meter are calibrated in two steps.

First, the output of a variable-frequency pulse generator is used to standardize both full-scale deflection and linearity of the four count-rate ranges, 0 to 100, 0 to 500, 0 to 5000, and 0 to 50,000 counts/sec. After any change in circuit values necessary to make this electronic calibration satisfactory, the detector is connected to a 100-channel pulse-height analyzer, and the γ-ray spectrum produced by so-called normal background is observed. Careful and repeated observation of the shape of the spectrum shows that the instrument threshold should be set slightly above 100 kV γ-ray energy, and the background count rate above this threshold is determined by integrating the data from the pulse-height analyzer. Next, the detector is connected to the count-rate instrument, and the threshold potentiometer is adjusted until the meter indicates the correct count rate. In our laboratory this is usually about 300 counts/sec. We are careful to insure that the background intensity does not change during these last two operations.

Second, we expose the detector, connected to its count-rate meter, to known radiation intensities provided by two radium-226 sources that have been certified by the National Bureau of Standards. One radium source contains the equivalent of 0.100 mg of radium and the other contains the equivalent of 1.35 mg of radium. The instrument is exposed to each of these sources at distances ranging from 5 to 10 ft, and the net counting rate (background subtracted) is then related to the radiation field produced by the sources in terms of mr/h. During this procedure, the scale linearity and full-scale deflection of each range are checked again. We find that the relation

$$500 \text{ counts/sec} \doteq 0.0122 \text{ mr/h} \doteq 0.107 \text{ r/yr}$$

is valid for all four instrument ranges. Because the spectrum produced by terrestrial gamma radiation is closely similar to that produced by our standard radium sources we believe that this conversion factor can be used in any field situation producing count rates less than or equal to the full-scale range of the instruments.

In practice, we have found that the calibration procedure with the pulse-height analyzer and pulse generator need not be repeated frequently. For field operations, calibration can be suitably made with a nonstandard radium source containing approximately 0.3 mg of radium and a disc source of uranium metal containing approx 6 g. When the instrument is correctly calibrated, the correct net count rate (background subtracted) must be observed when the uranium source is placed against the detector case on the end nearest the crystal. The γ-ray spectrum from the uranium source has a steep slope at the energy corresponding to the instrument threshold. Therefore, if the correct counting rate is observed, the gain, the threshold, and the high voltage on the phototube can be considered correct. Furthermore, our experience shows that correct response to a radium source is always given when the uranium-source response can be brought to the correct value by adjustment. Finally, since the instrument is used as a count-rate meter, cosmic ray events that produce very large pulses in the instrument are accounted for as one count per event and can be neglected. This is shown by the fact that in mineral environments containing no uranium, thorium, potassium, or fallout the count rate observed is less than 5 counts/sec.

D. Weatherproofing and Performance in the Field

For protection against rain and high humidity, the stainless steel detector case and the instrument case are fitted with rubber gaskets, and the high-voltage section in the instrument is potted with a silicone compound. Waterproof tape and thin polyethylene bags are also used occasionally to protect the instrument from moisture. When erratic instrument response occurred in the field, there was no evidence that this was due to moisture, either in the detector or the count-rate instrument, but rather that it was due to temperature sensitivity of the various transistor circuits; by using the uranium check source, it was always possible to make proper adjustment for this.

III. MEASUREMENTS

A. Egypt

1. Previous Work

Measurements made previously in the areas visited during the survey were reported in March 1961 in the Annual Report of the Committee on the Effects of Atomic Radiation of the Atomic Energy Commission of the UNITED ARAB REPUBLIC. These, and measurements by the United Arab Republic Health Physics Group, are based on readings taken with a scintillometer similar in operation to ours. The measurements indicated an exposure of 0.3 to 0.4 r/yr. The areas and the specific locations where the measurements were made were selected on the basis of a careful statistical sampling program designed to select populations that are equivalent in all respects except exposure to environmental radiation. Carefully drawn maps have been prepared showing the areas and the locations within them. These maps were used as the basis for our measurements.

2. Our Results

A summary of our measurements is listed in Table I. It shows that populated areas in the Nile delta are similar in terrestrial γ-ray exposure to the area near San Francisco Bay that we have studied since 1958. With few exceptions, our measurements of the exposures lie between 0.03 and 0.1 r/yr. Since these exposures are generally less than those referred to above, it was fortunate that we made our measurements simultaneously with another survey directed by the Health Physics Group of the United Arab Republic Atomic Energy Establishment. We were also able to cross-calibrate our instruments and theirs, using both our radium source and their radium source. The difference in response between our instrument and theirs to the same radium source was approximately 20%; our instrument read a few percent low and their instrument read slightly higher. This small difference between the responses of the two instruments was sufficient to explain any differences in the simultaneous measurements.

During the survey it was found that dry plant material--such as palm fiber, and ashes where plant material had been burned--gave generally higher readings than were found in the immediate vicinity. In our experience this may indicate the presence of fallout, and pulse-height analysis of this material in our laboratory confirmed this supposition. It is probable, therefore, that the higher readings previously reported by the United Arab Republic Health Physics Group were due in part to fallout.

The higher readings obtained in the interior of the older houses were most often due to the presence of thorium in bricks and sand used for construction. The newer houses, which use a different type of brick, give lower readings. Again, these field judgments were borne out by pulse-height analysis done in our laboratory on appropriate samples.

The low values measured along the SUEZ CANAL are due to the low concentrations of thorium, uranium, and potassium in the sand and to the desertlike character of the area, which supports little vegetation that may collect fallout. In the middle of the canal very small readings were obtained, and these show little more than the cosmic ray background. While these were being taken, an effort was made to use the instrument in such a way as to minimize the contribution from the launch and from the operator.

Table I. EGYPT

Place	Type of area	r/yr
ALEXANDRIA 29 December 1962	Indoors at Institute of Public Health	0.032
	Suburban asphalt-covered parking area	0.038
	Suburban canal bank	0.042
	Grassy lawn	0.042
	Secondary street	0.038
MARMORA 29 December 1962	Canal bank near water purification plant	0.040-0.044
MEADIA 29 December 1962	Along both sides of main road	0.042-0.052
EDKO 29 December 1962	Interiors of 10 new houses	0.032-0.042
	Interiors of 12 older houses	0.042-0.054
RASCHID (ROSETTA) 29 December 1962	Interiors of many new houses	0.043-0.054
	Interiors of many older houses	0.054-0.064
	Streets	0.054-0.064
	Interiors of palm-thatched houses	0.086-0.097
	Brick factory	0.062-0.086
	Next to a large block of granite	0.086
	Within a pile of palm fiber	0.086
ABOU KASHABA 30 December 1962	Sandy village streets	0.057-0.067
	Interiors of houses	0.054-0.097
	Outdoors in the vicinity of houses	0.062-0.075
	Interiors of barns	0.097-0.141
	Beach area where black sand is collected. Mediterranean seashore	0.171-0.241
	Within a pile of palm branches and fiber	0.171-0.211
	On a boat crossing the Nile River	0.004-0.006
ISMAILIA and SUEZ CANAL 30 January 1963	In the garden of the Suez Canal Company Headquarters	0.032
	At the dock of the Suez Canal Company	0.017
	Near Kilometer 73.7, east side of canal, inland	0.017-0.021
	Near Kilometer 74.2, west side of canal, inland	0.017-0.021
	Near Kilometer 74.2, along the canal embankment	0.013-0.015

Table I. (cont.)

Place	Type of area	r/yr
	Near Kilometer 82.3, east side of canal, inland	0.019-0.023
	Near Kilometer 86.8, west side of canal, around Tosson Station	0.019-0.021
	On the launch Hod-hod in the in the middle of the Suez Canal	0.004-0.006
	On the launch Hod-hod in the middle of Temsah Lake, Kilometer 78	0.003-0.004
	(Kilometer 0 is Port Said Lighthouse)	

B. India

1. Previous Work

The Effects of Radiation on Human Heredity, by the World Health Organization, Geneva, 1957, contains an article (pages 115-124) by A. R. Gopal-Ayengar, which discusses many aspects of the possible studies that could be made in this region. That report outlines the various types of radiation exposure possible in this area, discusses the main areas of the world where radiation levels are high, and gives several respresentative sets of measurements from villages in Kerala, comparing various parts of the villages on the beach, with respect to radiation inside and outside huts, as well as near and far from the sea. Possible implications of the special genetic situation within the Kerala population are also covered.

Another report, Measurements on the Radiation Fields in the Monazite Areas of Kerala in India, by D.S. Bharatwal and G. H. Vaze, Atomic Energy Establishment Trombay, Bombay 1, India, describes measurements made in the monazite areas of Kerala in more detail. The instruments used, the types of houses surveyed, the measurement technique, some of the results, and conclusions about these particular physical measurements are all discussed. A more recent summary of the situation is contained in the World Health Organization Technical Report, Series No. 166, The Effects of Radiation on Human Heredity, Investigations of Areas of High Natural Radiation, First Report of the Expert Committee on Radiation, World Health Organization, Geneva, 1959. This report, which includes the work of Bharatwal and Vaze in Tables 9, 10, and 11, is considerably more detailed and discusses the proposed project in Kerala at great length. It is a result of a five-day conference held at Geneva in 1958. This report again summarizes types of background radiation, discusses the γ-ray emitters contained in the rocks, and compares the several areas of the world with respect to such factors as their experimental potential, types of houses, and altitude.

The type of material needed for such an investigation and the many different approaches to the gathering of information are discussed. The proposed Kerala project is outlined, with maps and many details. The data are lumped by villages, types of houses, numbers of houses of each type scanned, and average γ-ray activity in millirads per year in these various situations. The variation within these houses is given, and the radiation screening by different types of construction material is treated. The toxicity of thorium is considered. Suggestions are made about the type of data that should be taken and the technique by which these should be gathered.

2. Our Results

The results of the measurements made in 1963 in the course of this investigation are listed in Table II. It can be seen that these new surveys with NaI detectors have been made in many of the areas covered by the previous work of Bharatwal and Vaze. Our measurements agree fairly well with those made about seven years ago by Bharatwal and Vaze with Geiger counter detectors. The range of the variations and the average values indicate that the radiation levels have been fairly constant in time. Although it is not clear at what season of the year the earlier surveys were made, it seems likely that the seasonal variation is not very great, at least in the living areas. The monsoon-produced seasonal variation is said to be fairly large along the beach high-water lines, but no direct measurements of this are available, nor does this variation seem to be a very important point so far as the overall dose to the population is concerned.

In the course of the surveys in the TRIVANDRUM area, an attempt was made to make rather careful surveys in areas where the radiation was known to be low, in order to evaluate them as potential control areas for any proposed study. The areas potentially useful as controls are separated in Table IV. The two areas found to be especially high in radiation, in agreement with the earlier work, are NEENDAKARA in Kerala State, and MANAVALAKURICHI in Madras State, also summarized in Table IV. Other intermediate areas are also listed.

The area at ATTIPRA was studied with unusual care, not only because it was the first village area we investigated, but also because it is the site of a public health unit, under the supervision of the medical college at TRIVANDRUM, which makes it a potential control area. The ATTIPRA area has been chosen for the future COSPAR-Indian Rocket-Launching Site because it is on the magnetic equator. Its value as a control area will perhaps be jeopardized in the future. At any rate, judging by the average values measured in this region, it would serve as a satisfactory control region from the radiation point of view.

TRIVANDRUM itself, because of its large population, should not be overlooked as a potential control area, although it has somewhat elevated values compared with some of the villages. Overall average values that we are able to give are certainly not likely to be very exact when it is realized that the fraction of the time the population spends in the various radiation regions may not be well represented as a fraction of the measurement we made in these areas. It would seem to be very risky to go much further than the breakdowns available in Tables II, III, and IV in trying to estimate the yearly doses to the population.

C. Ceylon

1. Previous Work

The approach to the radiation measurements in Ceylon was quite different from that in India. In Ceylon a detailed aerial survey had been made prior to our arrival, by a joint effort of the Canadian and Ceylonese governments. This aerial survey consisted of recording the counting rate of a scintillation counter mounted outside a flying boat that flew along a series of parallel lines, generally separated by 1/4 mile, and oriented in a north-south direction at a radar altitude of 500 ft (above the terrain, not above sea level). The integrating time of this scintillometer was 1 sec throughout the entire survey. One section, that of the ALUTGAMA area, was flown over at 300 ft, and with a 1/8-mile flight-line spacing. The elaborate colored maps produced by the Photographic Survey Corporation, Limited, of Toronto, were examined. All areas having a count rate greater than 3000 counts/min for 500-ft-altitude surveys or 5000 counts/min for the 300-ft-altitude surveys were outlined on a series of 1-to-63,360 or 1 in.-to-the-mile maps supplied to us by the Geological Survey of Ceylon. The ALUTGAMA area was the one surveyed at 300 ft elevation and was therefore known in more detail. (The different intensity-level cutoffs made allowance for the different altitudes flown.) Since the number of areas meeting these criteria was fairly large, it was not deemed reasonable to try to cover an equal number of control areas. It would seem, however, from the nature of the aerial surveys that control areas with quite low levels can be easily located merely by looking at these maps, which still reside in the office of the Geological Survey. Consequently, all areas listed in Tables III-A and III-B are intended to be high radiation areas having greater than 3000 and 5000 counts/min, respectively.

Table II. TRIVANDRUM-KERALA-INDIA AREA

Place	Type of area	r/yr
TRIVANDRUM 10 January 1963	Lawn	0.13-0.16
	Parking-lot-gravel	0.22
	Ground	0.29-0.40
	Parking-lot asphalt	0.11-0.13
	City street	0.20-0.25
MANVALA (near College of Engineering) 10 January 1963	Gravel road	0.16
	Uncultivated area	0.22
ATTIPRA (near midwifery center) 10 January 1963	Bare sand	0.25
	On railroad track balast	0.16
	Canal bank	0.090
ATTIPRA 13 January 1963	Road in village	0.22
	Village to canal	0.18-0.34
	Railroad to bridge	0.22-0.34
	Sand area	0.067
	Yellow sand	0.45
	Beach	0.045-0.090
	Shoreline, Arabian Sea	0.018
	25 ft from Arabian Sea	0.022
	Edge of palm grove	0.078-0.22
	Palm grove	0.11
	Bare ground along coast road	0.34
	"Alakali" lake	0.56
	Along canal bank	0.067-0.11
KULATHUR 10 January 1963	In village near rail	0.60
	Along railroad	0.20-0.22
	In deep hole in sand	0.18
	Open sand	0.22-0.34
	Along canal bank	0.11-0.13
VELI 13 January 1963	Tree line on beach	0.067
	Water line	0.011
	Road	0.067-0.090
	Hut area	0.067-0.090
QUILON 11 January 1963	Lawn near tourist bungalow	0.067-0.090
	In ACHTAMUDI Lake 15 ft from shore	0.0067

Table II. (cont.)

Place	Type of area	r/yr
QUILON-NEENDAKARA-PUTHENTHURA-CHAVARA 11 January 1963	Parking lot, Norwegian-Indian Health Center	0.67-1.1
	Village	4.5
	200 yds from beach	1.1-1.3
	Road	4.7
	Road	3.4
	Beach 50 ft from surf	7.2
	Beach 50 ft from surf	2.7
	School floor	4.5
	School yard	1.9
	Beach near surf	6.3
	Beach in front of large building	9.2
	Beach near wall, near factory No. 2	7.8-10.0
	Beach	>11
	In surf	4.5
	300 yds from surf	5.6-7.8
	In hut	4.0
	Road	5.8

Place	Type of area	r/yr Outside	r/yr Inside
NEENDAKARA 11 January 1963	Huts north of Norwegian-Indian Medical Center		
	1. Concrete floor, 1 brick wall + 2 thatch walls	2.0-2.7	1.1-1.3
	2. Concrete floor, thatch walls	1.6-2.2	1.6
	3. Concrete floor, thatch walls	1.1-1.3	1.1
	4. Dung floor, thatch walls	1.6-2.0	1.1-1.8
	5. Concrete floor, thatch walls	2.0-2.2	1.6-2.0
	6. Brick floor, thatch walls	1.1	0.67
	7. Dung floor, thatch walls	2.2-3.4	2.0-2.5
	8. Concrete floor, thatch walls	3.6-4.7	4.0-4.7
	9. Sand floor, thatch walls		3.8-4.0
	10. Concrete floor, thatch walls	3.1-3.8	3.4
	11. Concrete floor, thatch walls	4.3-5.4	2.9-3.4
	12. Concrete floor, thatch walls	4.5	3.6-4.5
	13. Mud floor, thatch walls	3.6-4.5	2.7-2.9
	14. Dung floor, thatch walls	2.9-3.6	3.6-4.7
	15. Dung floor, thatch walls	2.9-3.6	3.6-4.7
	16. Concrete floor, brick and plaster walls	3.6-5.8	1.3-1.6
	17. Sand floor, thatch walls	3.4-5.6	3.4
	18. Brick floor, thatch walls	3.4-5.6	2.7-3.4
	19. Brick floor, thatch walls	2.5-4.0	1.8-2.0
	20. Stone and concrete floor tile walls	0.67-0.9	0.38-0.40
	Average range	2.6-3.9	2.3-2.7
	Average	3.3	2.5

Table II. (cont.)

Place	Type of area	r/yr	
KALLURATHAKKAL	Quarry, grey rock	0.16-0.18	
12 January 1963	Red earth near quarry	0.22-0.25	
KADDAMBATTUKONAM	Rice paddy	0.20-0.25	
12 January 1963			
VARKALA	Along road	0.22-0.45	
12 January 1963	Beach away from water	2.20-11.0	
	Water's edge	0.45	
	Edge of stream	4.5	
NEDUNGANDA	Road	0.36-0.45	
	Beach	0.45-2.2	
	Outside of houses	0.45-0.67	
NEDUNGANDA	Huts	Outside	Inside
12 January 1963	1. Mud floor, thatch walls	0.45-2.2	0.78-0.90
	2. Mud floor, rock walls	0.45-1.1	0.40-0.76
KAYIKKARA	Beach	0.45-1.1	
12 January 1963	Hut area	1.3-1.6	
	Road	0.22-0.45	
	Lagoon	0.13	
	Side of road	0.56-0.67	
JMANJENGO	Beach	1.1-2.2	
12 January 1963	Hut area	1.6	
JMANJENGO	Huts	Outside	Inside
12 January 1963	1. Mud floor, thatch walls	1.1	0.90
	2. Mud floor, thatch walls	1.8	1.0
	3. Sand floor, thatch walls	1.8	1.1
	4. Mud floor, thatch walls	1.8	1.1
	5. Mud floor, thatch walls	1.6	1.1
	6. Mud floor, brick walls	1.6	1.3
KOTTILPAD	Average of 20 readings near church	0.99	
12 January 1963	Graveyard	0.83	
	Sand near beach	0.67	
	Crest of beach	0.78	
	By canal	0.67	
	Street by canal	0.67-1.1	
	Street by canal	1.3-1.6	
	Other areas	0.67-1.6	

Table II. (cont.)

Place	Type of Area	r/yr Outside	r/yr Inside
KOTTILPAD 12 January 1963	Huts	Outside	Inside
	1. Mud floor, stone walls	1.1-2.0	0.83
	2. Mud floor, thatch and brick walls	1.6	1.3
	3.	1.3	1.3
	4. Mud floor, thatch walls	0.90	0.90
	5. Mud floor, brick and plaster walls	1.1	1.3
	6. Mud floor, brick and plaster walls	0.90	1.3
	7. Mud floor, adobe walls	1.3	0.90
	8. Concrete floor, stone walls	0.90-1.1	0.90-1.1
	9. Concrete floor, stone walls	0.90-1.1	0.83
	10. Concrete floor, stone walls	0.90-1.1	1.1-1.6
	11. Concrete floor, stone walls		0.90-1.1
	12. Concrete floor, stone walls		0.45-0.72
MANAVALAKURICHI 12 January 1963	Huts		
	1. Mud floor, brick and plaster walls	5.6	6.7
	2. Mud floor, thatch walls	4.7	4.9
	3. Tile and concrete floor, brick and plaster walls	4.9	3.4
	4. Dirt floor, brick, stone, and plaster walls	6.7	6.0-7.4
	5. Concrete floor, brick and plaster walls	5.4	3.4
	6. Brick floor, stone, brick and plaster walls	7.8	5.6
	7. Mud floor, brick and plaster walls	10.	6.5
MANAVALAKURICHI 12 January 1963	Near Factory No. 3		
	Village	2.2-3.8	
	Dump	10-11	
	Beach near village	4.5-4.9	
	Beach near Arabian Sea	0.22-2.2	
	Street	1.1-2.5	
	Market	2.5-3.1	
	Compound No. 1	2.2	
	Road in front of compound	1.6	
	Compound No. 2	1.6-1.8	
	Road in front of compound	0.67	
	Compound No. 3	1.8	
	Compound No. 4	2.2-2.5	
	Well in compound	0.45	
	Town south of market	2.2-4.5	
	Road south of market	0.67-1.1	

Table III-A. Ceylon - South of COLOMBO

Place	Type of area	r/yr
PANADURA 16.5 MS*	Yard	0.21
16 January 1963	Side of road	5.4
	Average of 28 readings along city streets and in yards	0.56
POTUPITIYA 22.5 MS	Ocean side of road	1.2
16 January 1963	Ocean side of road	1.5
	Land side of road	0.84
	Land side of road	0.76
PIYAGALA SOUTH 31.5 MS	North of main railroad crossing West of road	0.65
17 January 1963	South of main railroad crossing	
	West of canal	0.48
	East of canal	0.45
POLKOTUWA 34 MS	West of railroad and north of church	3.2
17 January 1963	West of railroad and south of church	1.6
BANDARAWATTA 40 MS 17 January 1963	South to canal both sides of road	0.22-2.2
ALAKANDUPITIYA	East of temple	1.2
17 January 1963	West of temple	0.24
KAIKAWALAGALA 42 MS	West of railroad, north of 42 MS	3.2
17 and 18 January 1963	West of railroad, south of 42 MS	6.9
	Coates Mineral site	> 11.
	Inside house	3.3-5.6
KOSGODA 45.5 MS	Near police station	0.32
17 and 19 January 1963	East of railroad	2.0
AHUNGALA 47 MS	New beach	2.2
17 January 1963	Near large rock	0.27

* MS = milestone measured from center of Colombo.

Table III-A. (cont.)

Place	Type of area	r/yr
UNAGASWELA-PUNCHI-PANAPITIYA 80° 04.5' E, 6° 16.5'N (turn at MS 53) 19 January 1963	New beach	2.2
	Near large rock	0.27
	In village	0.32
BOPE (hill NE of MS 71) 19 January 1963		2.4
GINTOTA MS 69.5 19 January 1963	West of road	0.81
MAHAHPUGALA (turn at 68.8 MS) 19 January 1963	East of road	1.1
KADURUPE 68.4 MS 19 January 1963	East of BUSSA racecourse	0.19
	Rubber plantation	4.9
RANAPANADENIYA (turn at 65.5 MS) 19 January 1963	Both sides of road	0.42
PATANA (turn at 62.5 MS) 19 January 1963	Near settlement	0.73
KATUKOLIHA (turn at 63.7 MS) 19 January 1963	East of road	0.75
DONDRA HEAD 103.8 MS	Along road	0.75
	Local area south of road, east of bridge	5.1
KAPUGAMA 104 MS	Near post office, north of road	0.16
WERAGAMPITA	NE part of MATARA	0.033
HITTETIYA	North of MATARA 1.5 mile	0.90
DIKWELLA 20 January 1963	Near temple	0.43
WALASGALA 20 January 1963	Near temple	0.42

Table III-A. (cont)

Place	Type of area	r/yr
ARATTANAGODA (5 mile N 112.5 MS) 20 January 1963	Citronella planting	0.31
KUDAHILLA 20 January 1963	Citronella planting	0.11
KEMAGODA 114.3 MS	Coconut grove	0.58

Table III-B. Ceylon - North of COLOMBO

Place	Type of area	r/yr
ATPUTA 11 MS 21 January 1963	Along road	0.22
HORAKELE (1 mile E 38.7 MS) 21 January 1963	Coconut grove	0.022
	Small area 100 ft across	0.27
SETTAPPADUWA (7 mile from 13.5 MS on main road on west side of NEGOMO LAGOON) 21 January 1963	Outside houses	0.53
	Inside houses	0.44
KEPUNGODA (6 mile from 13.5 MS on main road on west side of NEGOMBO LAGOON)	Outside houses west of road	1.0
	Inside houses west of road	0.59
	Outside houses east of road	0.81

Table IV. Summary of areas in India

Type of area			r/yr
Low-level areas; all readings < 0.5 r/yr; 55 readings			
TRIVANDRUM, MANAVALA, ATTIPRA, VELI, KULATHUR, QUILON, KALLURATHAKKAL, KADDAMBATTUKONAM			0.18
Medium-level areas, all others except NEENDAKARA and MANAVALAKURICHI			
	Outside	59 readings	1.3
	Inside	26 readings	1.0
High-level areas			
NEENDAKARA	General areas	21 readings	5.0
	Outside huts	19 readings	3.3
	Inside huts	40 readings	2.5
MANAVALAKURICHI			
	General areas near main road	19 readings	3.1
	Compounds along main road	6 readings	2.0
	Outside huts near beach	7 readings	6.4
	Inside huts near beach	8 readings	5.5
Average, weighted, for high-level areas			
	General		4.1
	Outside (including compounds)		3.6
	Inside		3.0

2. Our Results

It can be seen immediately from looking at the data in Tables III-A and III-B that these areas are not uniformly intense in their ground-level radiation. In fact, some areas that appear on the aerial surveys to be quite intense are noticeably low when measured on the ground. The reason for this apparent inconsistency between air-borne and ground measurements is not completely clear at this time. Areas measured by the Ceylonese Geological Survey and indicated by their measurements to be of high radiation level proved to be so in every case when we made our measurements. In several cases, not checked on the ground by the Ceylonese Geological Survey, especially near the south end of of the island, it is seen that the areas indicated by the aerial survey have either undergone a change since 1959 or were not properly located by us on the ground.

This latter possibility seems unlikely in view of the extremely good maps that were made available to us by the Ceylonese Geological Survey. There may have been some difficulty with the detector in the airplane. With regard to this possibility it should be noted that in the aerial survey--for example, of the Alutgama area--there is a preponderance of high radiation values arranged in a north-south compass direction exactly parallel to the flight lines and not paralleling any geological structure. This particular phenomenon was observed in several places and is certainly not understood, because apparently great pains were taken to insure the accuracy of the aerial surveys. Consequently, this apparent tendency for high radiation values to be detected in north-south lines along the flight lines is perhaps a systematic effect. Several of the sites that were expected to be high in radiation level, but that when visited on the ground were found not to be, were in these strongly north-south oriented patterns. This particular inconsistency probably does not invalidate the conclusions in this measurement nor indicate any need for further study.

IV. CONCLUSIONS AND INCIDENTAL REMARKS

A. Egypt

1. Good agreement was found between the response of our instruments and those used by the United Arab Republic Health Physics Group.
2. Population in the area surveyed is concentrated in towns and villages. The beach area where black sand is collected has no permanent inhabitants.
3. The magnitude and variation in radiation intensity within inhabited locations was smaller than those observed in India and Ceylon.

B. India

We can make some generalizations from the data from India.

1. Roadways usually have a lower radiation level than bare ground because the roadbed material and the surface material seem to be largely foreign to the region and generally brought from areas of harder rock further inland.

2. The sand, aggregate, and cement used in the concrete throughout the regions of all the surveys we made seem to be universally lower in radioactivity than the bare ground.

3. Radiation levels inside dwellings are almost always lower than those outside. This change is perhaps as much as 30%; even though the material of which the house is constructed may be largely native and rather thin, it still offers a modest amount of shielding. This is especially true when the floor of the dwelling is concrete rather than sand, or sand and dung mixed. House No. 8 in Neendakara was a slight exception to this rule. The average values for the 20 houses in NEENDAKARA, however, gave a 25% reduction for the difference between outside and inside radiation levels. In the case of MANAVALAKURICHI the reduction is somewhat larger. Huts No. 1 and No. 2 in MANAVALAKURICHI also had higher levels inside than outside.

4. In those cases for which we were able to get away from the monazite radiation, for example, 15 ft out on ACHTAMUDI LAKE near QUILON, the levels dropped to the very low value that one would expect from cosmic rays over water near the equator. It should be remembered in this connection that our instruments were especially intended to neglect the effect of cosmic rays. It is gratifying to

notice that this was apparently achieved, even QUILON itself is very near some of the areas of highest terrestrial radiation.

It was our habit in making these surveys to stick the detector as far down as possible in any well that we found, since wells in this area were all lined with poured concrete or concrete blocks. They provided a locally shielded region from the natural radiation. The concrete is not particularly radioactive, and in all cases the radiation rate in the well was found to be considerably reduced, by perhaps a factor of 2, relative to that just barely outside. In those regions where monazite and ilmenite sand was being actively deposited by the surf, the highest radiation values were generally measured near high-water lines. This was not the case in those areas where this deposition was not currently occurring. The high radiation levels are also associated with the areas of previous beaches.

One should be careful to note that several of the areas we visited are somewhat influenced by monazite and ilmenite separation plants put into operation during the last fifty years or so. The tailings from the monazite and ilmenite separation plants generally are quite radioactive and may influence an area of several acres in which people are presently living. These tailings tend to be spread around as time goes on, and thus affect larger adjacent areas. Regions subject to such concentration effects are at the northern end of the NEEDAKARA area near factory No. 2 of the Chavara Mineral Company, Limited. However, apparently most of the NEENDAKARA village area is not subject to this artificial concentration effect.

In view of the values contained in Table II, it would seem that the most fruitful areas for further investigations are NEENDAKARA and MANAVALAKURICHI. In addition to these, VISHAKAPATNAM and WALTAIR are known to have high levels, but both are east of CAPE COMORIN and were not investigated. Of all the areas it would seem that MANAVALAKURICHI is potentially the most promising for further study, in view of the coincidence of high population and dose levels.

C. Ceylon

A difference between the Ceylonese regions and Indian regions is that usually the Indian high-level areas were in villages or along the beach in regions where a considerable number of people live. Many of the Ceylonese radiation zones were further inland in more agricultural areas. In fact, the beach itself often turned out to be relatively low in radiation levels. This would indicate that the monazite producing the high radiation values is of somewhat older geological structure than that in India and was laid down on prehistoric beaches. The main result of this particular situation is that many of the high radiation areas have a much lower population density than those in India. The population in both countries is concentrated along the coastal road fairly near the ocean. Thus in Ceylon quite a number of areas were found that were of potential interest from their radiation levels but that were unpopulated. Frequently the high radiation areas were quite limited in extent, and often located in palm groves or in rubber plantations, and therefore not particularly interesting with respect to human whole-body radiation.

A third factor that is different in Ceylon is that many of the houses in areas where the radiation level was rather high are so well constructed--usually of concrete or tile--that they offer excellent radiation shielding, with the consequence that the radiation levels inside the houses is much lower than that outside; this greatly reduces the overall dose to the population. In fact, the populated areas of Ceylon with reasonable values of radiation, would seem to be KAIKAWALAGALA, POLKOTUWA, KOSGODA, POTUPITIYA, and KEPUNGODA. None of these compares in population intensity to Manavalakurichi and Neendakara in Kerala. In these areas there is extreme variability of the radiation levels in short distances like a few yards, and the excellent shielding offered by the very solid Ceylonese house construction would require that an individual survey be made in each home from which biological data are to be taken. For example, it would be rather meaningless to try to make an overall estimate of the radiation in a particular village, because many inhabitants might only rarely go near the very localized high-radiation areas or might live in houses that would protect them from a large fraction of the ambient external radiation.

These factors certainly complicate the conclusions that might be obtained from a study in Ceylon. It is conceivable that some sort of personal dosimeter might be supplied to individuals from whom biological data are being gathered, and that this dosimeter might measure this individual's total exposure over some period of time, to compensate for dose-rate fluctuations. Spot checks with survey instruments of the type we used would serve to indicate which specific areas are worth further study on an individual basis. It is not reasonable, however, from the experience which we gained in CEYLON, to expect to study an entire village--as might be possible in the case of MANAVALAKURICHI or NEENDAKARA--with the assumption that the same general average background radiation level could be applied to everyone in the village with some modest degree of reasonableness. In addition, in view of the air survey, it appears that there are probably no other areas in CEYLON that have monazite deposits and extensive populations. On the other hand, it is conceivable that there are one or two other areas each of CAPE COMORIN in Madras State in INDIA that might be as well worthwhile as NEENDAKARA (Kerala State) or MANAVALAKURICHI (Madras State).

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