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ABSTRACT

A radiation survey has been made in three monazite sand areas in Africa and southern Asia, with 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 survey was made in Egypt, 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 beaches both north and south of the city of Trivandrum, from January 10 through January 13, 1963. The third survey was carried out in southwestern Ceylon, north and south of the city of Colombo, from January 15 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. Other important questions, such as individual whole-body and internal exposures, the number of people and the amount of time they spend in the areas where the radiation surveys were made, the interpretation of their biological condition, and any effects the radiation fields may have on the populace as a whole, are being carefully investigated by the governments involved and some results of these investigations have already been reported.

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INTRODUCTION

We and our co-workers in the Health Physics Department of the Lawrence Radiation Laboratory have, for a number of years, made various kinds of measurements of the natural radiation environment. These were mostly for the purposes of estimating, as closely as possible, the external whole-body exposure of individuals, and determining the cause and means of reduction of background in NaI detectors.[1-4] We have concluded that it is absolutely essential to a proper understanding of this environment that the radiation components in it be identified and measured separately. For example, if one wishes to measure gamma radiation for the purpose of estimating whole-body, bone-marrow, or gonadal doses, then one should use a detector that is specifically sensitive to gamma radiation and in which the response to beta and cosmic radiation is strongly suppressed.

Geiger tubes and ion chambers are generally not suitable or selective detectors for gamma radiation because their response to beta and cosmic radiation is enhanced, they are directional, the small signal developed in them at normal background levels leads to uncertain statistics, and not much care is taken in manufacture to eliminate inherent background. On each of these particulars, a NaI crystal viewed by a phototube and connected to a rate meter is superior. We found this point of view to be shared by our associates in the surveys in Egypt, India, and Ceylon, but it has not been recognized or well understood by health physicists here in the United States.[5]

This report calls to the attention of health physicists the very great variation of terrestrial γ-radiation intensity, and describes an instrument that has the necessary selectivity and sensitivity to measure only this component of the radiation environment.

I. MONAZITE

The three areas surveyed are mostly wave-deposited beach sands of monazite that emit γ rays owing to their content of thorium. Monazite is a mixed phosphate of the cerium metals--cerium, lanthanum, and dysprosium. Small amounts of thorium oxide (between 1 and 10%) are possible spatial substitutions in the crystals for the cerium. Monazite crystals are monoclinic and are generally a dull, opaque reddish brown, with hardness about 5.5, and density between 5.1 and 5.2.

The crystals usually separated for commerce are between 0.1 and 0.2 mm in size and are most frequently found with ilmenite and rutile, both of which produce so-called "black sand." Thus monazite deposits often appear as black streaks on the beach. However, because 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.

Commercially significant deposits of monazite occur in the beach sands of North Carolina, Brazil, Ceylon, Australia, and several other regions around the world, but the world's richest known and most extensive deposit of monazite sands occurs in southern India in the state of Kerala.

II. DESCRIPTION OF EQUIPMENT

A. Transistorized Rate Meter

The transistorized count-rate meter was designed by W. W. Goldsworthy and is reported in Nucleonics.[6] His design has been slightly modified for our purposes, but remains 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 approximately 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 quickly made. 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 us 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 (in mr/h) produced by the sources. During this procedure, the scale linearity and full-scale deflection of each range are checked again. We find that the relation

500 counts/sec = 0.0122 mr/hr = 0.107 r/yr

is valid for all four instrument ranges. Because laboratory pulse-height analysis of many samples shows that 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 not greater than 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 carried out with a nonstandard radium source containing approximately 0.3 mg of radium and with a disk source of uranium metal containing approximately 6 g of uranium. When the instrument is correctly calibrated, it must indicate the correct net count rate (background subtracted) 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 or to terrestrial radiation 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 countrate meter, cosmic ray events that produce infrequent but very large single 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 10 counts/sec at sea level.

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; rather 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 deviation.

III. MEASUREMENTS

A. Egypt

1. Previous Work

The careful study and measurements made previously in the areas visited during this survey were reported in reference 7. These, and concurrent measurements by the United Arab Republic Health Physics Group, are based on readings taken with a scintillometer similar in operation to ours. The past measurements indicated an exposure in some areas 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 were prepared by the UAR showing the areas and the locations within them, and these maps were used as the basis for our measurements.

2. Results

A summary of our measurements is presented in Table 1. 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 with 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 somewhat high. 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 Republich 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, as expected.

B. India

1. Previous Work

The Indian Government and the World Health Organization, to whom we acted as consultants, have long been aware of the potential usefulness of the Kerala-Madras beaches for studies of the effects of radiation on human heredity. Preliminary surveys that implied yearly exposures in the range 0.050 rad to 4.0 rads, and plans for studies, have been reported in references 8-10.

2. Results

A summary of our measurements made in 1963 is set forth in Table 2. These surveys with NaI detectors were made in many of the areas covered by the previous work of Bharatwal and Vaze, and our measurements are in good agreement with theirs. The range of the variations and the average values indicate that the radiation levels have been reasonably constant, and it seems likely that the seasonal and yearly variation is not very great.

C. Ceylon

1. Previous Work

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 an airplane that flew along a series of parallel lines, generally separated by 1/4 mile, 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 300-ft-altitude surveys) were outlined on a series of 1-to-63 360 (1-in. -to-the-mile) maps supplied to us by the Geological Survey of Ceylon and then measured by us on the ground.

2. Results

It can be seen immediately from looking at the data in Tables 3-A and 3-B that these areas are not uniformly intense in their ground-level radiation, as one might expect from the aerial survey data. In fact, some areas that appeared on the aerial surveys to be of high intensity were not found so on the ground. The reason for this inconsistency between air and ground measurements is not completely clear. However, all ground measurements made with a scintillometer by the Ceylonese Geological Survey were in good agreement with ours.

IV. GENERAL OBSERVATIONS

1. Good agreement was found between our measurements and those made previously in India and simultaneously in Egypt and Ceylon.
2. Radiation levels measured with the detector in a car or over paved areas are generally lower than those made over soil, grass, and sand.

3. In India and Ceylon radiation levels inside buildings and dwellings are generally lower than outside.

4. Aerial survey data are difficult to translate into ground-level intensities.

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Table 1. Egypt

Place	Area	r/yr
Alexandria 29 December 1962	Streets, lawns, interiors of buildings	0.032-0.042
Marmora 29 December 1962	Canal banks	0.040-0.044
Meadia 29 December 1962	Along 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
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 1 January 1963	Garden and dock of the Suez Canal Company Headquarters	0.017-0.032
	Both banks of Suez Canal, km 73.7 to km 86.8 (kilometer 0 is Port Said Lighthouse)	0.017-0.021
	On a launch, middle of Temsah Lake	0.003-0.004

Table 2. Summary of areas in India (in Kerala and Madras).

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 houses	59 readings	1.3
	Inside houses	26 readings	1.0
High-level areas			
Neendakara			
	General areas	21 readings	5.0
	Outside houses	19 readings	3.3
	Inside houses	40 readings	2.5
Manavalakurichi			
	General areas near main road	19 readings	3.1
	Compounds along main road	6 readings	2.0
	Outside houses near beach	7 readings	6.4
	Inside houses near beach	8 readings	5.5
Average, weighted, for high-level areas			
	General		4.1
	Outside houses (including compounds)		3.6
	Inside houses		3.0

Table 3-A. Ceylon, South of Colombo.

Place	Area	r/yr
Panadura 16.5 MS* 16 January 1963	Along roads, city streets, and yards	0.21-5.4
Potupitiya 22.5 MS 16 January 1963	Ocean side of road	1.2-1.5
	Land side of road	0.76-0.84
Piyagala 31.5 MS 17 January 1963	Along roads, city streets, and yards	0.45-0.65
Polkotuwa 34 MS 17 January 1963	Outdoors near church	1.6-3.2
Bandarawatta 40 MS 17 January 1963	South to canal both sides of road	0.22-2.2
Alakandupitiya 17 January 1963	Outdoors near temple	0.24-1.2
Kaikawalagala 42 MS 17-18 January 1963	Outdoors, north and south of 42 MS	3.2-6.9
	Coates Mineral Co. site (artificial concentration)	> 11.
	Inside house at Coates Mineral Co.	3.3-5.6
Kosgoda 45.5 MS 17 and 19 January 1963	Along roads, city streets, and yards	0.32-2.0
Ahungala 47 MS 17 January 1963	On beach	0.27-2.2
Unagaswela-Punchi-Panapitiya 80° 04.5' E, 06° 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

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*MS = milestone measured from center of Colombo

Table 3-A (cont.)

Place	Area	r/yr
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
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 3-B. Ceylon, North of Colombo.

Place	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 Small area 100 ft across	0.022 0.27
Settappaduwa (7 miles from 13.5 MS on main road on west side of Negombo Lagoon) 21 January 1963	Outside houses Inside houses	0.53 0.44
Kepungoda (6 miles from 13.5 MS on main road on west side of Negombo Lagoon)	Outside houses west of road Inside houses west of road Outside houses east of road	1.0 0.59 0.81