DOSIMETRIC MEASUREMENTS IN BRAZILIAN REGIONS OF HIGH NATURAL RADIOACTIVITY LEADING TO CYTOGENETIC STUDIES*

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Abstract—Several Brazilian regions of high natural radioactivity provide excellent opportunities to study effects of chronic exposure to low level radiation and groups from Catholic University, New York University and University of Brazil joined in a cooperative investigation.

In the monazite sand zone external levels are elevated and people live in intimate contact with surface contamination. On beaches levels run as high as 2 mR/hr and in homes up to 0.6 mR/hr. Three sources of exposure are considered: external γ-radiation; internal contamination with long-lived radioisotopes; internal contamination by thoron daughter products.

A survey with lithium fluoride dosimeters showed an average external exposure of 750 mR/yr with a range from 160 to 2500 mR/yr. Measurements of thoron exhaled in breath indicate body burdens of 0.1 to 0.6 nCi of MsTh, although the data is ambiguous. A whole body counter is under construction using sugar as shielding material. Thoron concentration in homes is measured by electrostatic capture on steel cylinders and measurement in ionization chamber.

Using peripheral blood techniques the cytogenetics group has found a much higher frequency of chromosomal aberrations in the exposed than in the control group, although data are still insufficient.

Two sites have been chosen in the region of volcanic intrusives, Môrro do Ferro, near Poços de Caldas, and Araxá.

Môrro do Ferro with levels up to 3.2 mR/hr is a center for studies leading to radioecology. Soil–grass and soil–plant studies show concentrations of ^{226}Ra in grass and plants up to 10^3 pCi/g ash. Rats live in a thoron environment of up to 10^{-8} Ci/l.

In the Araxá farmland soil–food stuff relations are studied. The cytogenetic study will center on the small number of families who subsist mainly on food from the radioactive farms.

THE areas of the world with high natural radioactivity might provide us with valuable information on the long-term effects of chronic exposure to low level radiation. It is the purpose of this paper to discuss one aspect of the work done in the monazite area of Brazil.

Guarapari is a city of 6000 people in the State of Espírito Santo on the Atlantic coast. The interplay of river and ocean currents has built the sand bar on which the town sits. Black sand is found in patches and in layers on the beaches, under the town, and has found its way into construction material. The black sand is composed of ilmenite, rutile, and monazite. Monazite is a combination of rare earth phosphates with 6% thorium and 0.3% uranium impurities. It can give rise to external levels as high as 1.2 mR/hr and abrupt gradients.

The geological origins of the monazite sand [1] and the early surveys of external radiation levels [2] have been described. Three years ago a coordinated multi-discipline approach to the studies in the several areas was begun by the Institute of Physics, Catholic University,

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the Institute of Biophysics, University of Brazil and the Institute of Environmental Medicine, New York University.[3]

The Institute of Biophysics has been conducting a cytogenetic study of the population of Guarapari and the smaller but similar town of Meaipe. As a control population the town of Anchieta, with similar social and economic conditions, has been chosen.

A cytogenetic study requires meticulous care and time. While the group has not processed a sufficient number of control samples they are able to make the following statement.

"Preliminary findings of our cytogenetics laboratory, however, did indicate a significant increase in the frequency of somatic chromosome aberrations of Guarapari's inhabitants, in comparison with controls. A high incidence of multiple break chromosomal aberrations was found, which is more compatible with the interpretation of being caused by alpha and beta radiation from internal emitters, rather than by gamma radiation."[4]

The Institute of Biophysics has also radiochemically analyzed foodstuffs, teeth and excreta. Local foods constitute only a small part of the diet. The analysis of teeth and excreta has not given conclusive results.

The Catholic University group conducts dosimetric studies along three lines: external levels; thoron in the air; body burdens by breath analysis and whole-body counting.

Social and hygenic conditions of the people set boundaries to the work. Infant mortality is high and would mask any visible effect in a classical epidemiological study, even if the population were large enough. They are simple people who are afraid of a big city and suspicious of complicated looking apparatus.

1. EXTERNAL RADIATION LEVELS— THERMOLUMINESCENT DOSIMETERS

Lithium fluoride dosimeters are used to integrate over a long period of time the dose rate received by selected individuals as they moved through the variable gamma field. The packets consisted of Type N phosphor (Conrad) and were enclosed in a medal hung from the neck.

The cytogenetic study determined the aim and protocol of distribution. The aim was to reconstruct, if possible, the life time dose of an individual once his life history is known. For this reason they were distributed in different sections of the city, to all age brackets and to both sexes.

During the first phase of the study 156 dosimeters were distributed in May 1964 and left with the people for three months. Of these 115 were recovered in good condition.[5] In the end of September 1965 another 384 were given out. This time they were more widely distributed through Guarapari, in the newer suburbs, in another monazite town, Meaipe, and in the control city of Anchieta. After six and seven months, hunt and find expeditions were only able to locate 225 of these dosimeters.

The dosimeters were returned to Conrad for readout services. Two corrections were applied to the data received. O'Brien, Lowder and Solon have calculated the fraction of free air dose rate received from terrestrial sources as a function of the radiation energy and depth in man.[6] At zero depth the fraction ranges from 0.687 at 0.375 MeV to 0.735 at 2.25 MeV. Here the average of 0.70 was used to reduce the data to air equivalent dose rates.

The second correction was a result of calibration experiments. For both years sets of dosimeters were exposed to standard radium sources with doses at the level expected in the field. They were then kept at normal levels together with unexposed dosimeters and sent to Conrad with the full collection. The calibration slope for the first experiment was 0.92 and for the second 0.90. This may have been due to fading in a tropical country. A correction factor of 10% was applied to all data.

The average dose rate for the 317 people measured in the exposed population is 636 mR/yr with a minimum of about 100 mR/yr and a maximum of 3200 mR/yr. The data are presented in Table 1, grouped according to neighborhoods and towns. The neighborhoods of Guarapari are designated by certain street names and are listed in the order of descending external levels. The distribution of dose rates received by the exposed population is given in Table 2.

The first observation that can be made is that the movement of daily life tends to equalize dose rates. The highest external levels are found

Table 1. Average Air Equivalent Dose Rates received by samples of populations of Guarapari, Muquiçaba, Meaipe and Anchieta, Brazil

Town and neighborhood	No. of people	Dose rate (mR/yr)
Guarapari		
Pedro Caetano	85	785
Sizenandro Bourgninon	32	608
Joaquim Lima	31	594
Getulio Vargas	24	549
Henrique Coutinho	24	514
Church Hill	22	393
Muquiçaba and other suburbs	65	562
Meaipe	33	777
Anchieta	23	98

Table 2. Dose Rate Distribution in Radioactive Towns, Brazil

Range (mR/yr)	No. of people
0– 99	0
100– 199	23
200– 299	42
300– 399	47
400– 499	47
500– 599	40
600– 699	26
700– 799	15
800– 899	14
900– 999	10
1000–1099	8
1100–1199	9
1200–1299	4
1300–1399	5
1400–1499	5
1500–1599	2
1600–1699	7
1700–1799	0
1800–1899	2
1900–1999	3
more than 2000	5

in Pedro Caetano, which also happens to have a concentration of people. The doses are lower than one would expect, because people move from home to work or to school The external levels on the Church Hill and in Muquiçaba, on the other extreme, are hardly above normal but these people also move into the town for work, school and medical services.

The individual's annual dose is a function of his home, his age and his work, and the presentation of average data tends to obscure the wide difference existing. One elderly couple on the main street receives annual doses of 199 and 212 mR. Around the corner in another home the individuals received 1560, 1310, 1670 and 1190 mR., the smallest being that of a school girl. On Getulio Vargas Street a doctor and his wife receive 1220 and 1210 mR while a man two doors away receives 215 mR.

In the winter survey of 1964 the people in Pedro Caetano received an average dose of 714 mR while in the summer months of 1965–6 the average dose was 540. This is due not only to the fact that in the heat they tend to remain outdoors but also because several families rent their homes to vacationers and live in another section.

A monazite separation plant, Mibra, was closed down in December 1963 but has maintained a skeleton staff. In 1964 these workers, because of rejected sand left nearby, received an annual dose of 990 mR and in 1965–6 1015 mR. The rejected sand, with levels of 0.25 mR/hr, is used as a football field by youngsters and contributes to the level of the population on Sizenandro Bourgninon Street.

School dropouts receive higher dose rates than children who remain in school, but further grouping of data according to age or sex would fail to show any significance. The aim of the survey was to assess the dose rate received by individuals of different ages and occupations who lived in certain homes. A sufficiently large body of data exists now that reasonable estimates can be made.

The opinion of the cytogenetics group in the Institute of Biophysics however is that the aberrations observed are not due to external radiation.

The people in the control town of Anchieta received approximately normal levels, as was expected.

2. THORON IN THE AIR

An important contribution to the internal dose rate can come from the concentration of thoron in closed bedrooms, with the subsequent deposition of decay products in different body organs. Scintillometer readings of 0.1 to 0.6 mR/hr next to walls in the homes showed the possibility of high thoron concentrations in the air.

Some attempts to measure the concentration have not met with complete success. Staplex filter measurements in the streets show the presence of daughter products of the order of 0.3 pCi/l.

This year an electrostatic deposition method was attempted in closed rooms. Sheets of stainless steel were mounted in a cylindrical frame. A voltage source maintained an inner electrode at a positive potential of 1000 V. The decay products of thoron and thorium A are captured on the inner surface of the metal. The metal is then placed in a 4 liter ionization chamber and the current read with a vibrating reed electrometer.

The apparatus itself gives satisfactory results and thoron is measured. What was not foreseen, however, was the reluctance of some people to permit a strange looking metal object in their rooms at night. A further problem is the impossibility of installing a fan and, without circulation, the readings have no certain meaning. It is estimated that the concentrations are above 1 pCi/l.

A further attempt was made with the apparatus designed by Robert T. Drew of New York University, to measure the high concentrations in rat holes on Morro do Ferro. A sample of air is drawn into a 200 ml flask, coated on the inside with zinc sulfide, and the sample is alpha counted. Eleven measurements made in a rainy period showed negative results. It is estimated that the concentration at that time was less than 4 pCi/l.

3. BODY BURDENS

(a) *Measurements of Thoron in Breath*

Because the cytogenetic data suggested the presence of internal contamination, measurements of thoron in breath were resumed. This is an easy and, at the time, the only available method of testing for the presence of mesothorium in the body.

The method, elaborated by Dudley, relies simply on the fact that a certain fraction of the thoron produced in the body is exhaled. A person is asked to breathe for an hour into a 50 liter soup pot. Through the top is suspended a 1 in. brass disk connected to—8000 V. The recoil nuclei of the decay products of thoron and thorium A are electrostatically

Table 3. *Body Burdens inferred from Thoron-in-breath Measurements, Guarapari*

Subject	Sex	Age	Occupation	Mibra*	^{224}Ra (nCi)
A	F	47	Housewife	—	0.52
B	M	50	Owns bar	25	0.28
C	F	17	Bakery	—	0.23
D	M	46	Owns bar	12	0.20
E	F	38	Housewife	—	0.16
F	M	39	Mibra	25	0.45
G	F	18	Telephone	—	0.31
H	M	43	Mibra	25	0.31
I	M	16	Mechanic	—	0.29
J	M	56	Mibra	25	0.22
K	M	17	Student	—	0.22
L	M	57	Office	—	0.18
M	F	22	Pharmacy	—	0.16

* Mibra: Years of work in monazite separation plant. Plant closed December 1963.

captured. The disk, which has been covered with a layer of zinc sulfide, is placed on a similarly covered phototube. Each disk is alpha counted for several hours and only four can be counted per day.

A large uncertainty remains in the results because of the unknown efficiency of exhalation. If the mesothorium is an old deposit in the skeleton only 0.1% is exhaled. If it is in the liver or spleen 8% is exhaled. The apparatus was tested several years ago with three thorotrast patients and confirmed the figure of 8% exhalation.

The data for 13 subjects from Guarapari are given in Table 3. An exhalation efficiency of 8% is assumed, thereby giving the lowest estimate of body burdens. It is possible that this is wrong by more than an order of magnitude. The decay curves are given in Fig. 1.

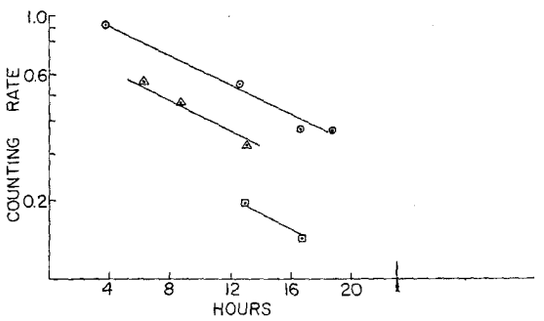

FIG. 1. Typical decay curves for thoron-in-breath measurements.

The choice of subjects centered on families who have lived all their lives in Guarapari, but the definite selection was based on a list of people with chromosomal damage furnished by the Institute of Biophysics. The subjects listed under letters A, H and L are known to have chromosomal aberrations.

(b) *Whole-body Counting "The Sugar Bowl"*

Since the thoron-in-breath measurements indicated a body burden of less than 1 nCi and this could be wrong by more than an order of magnitude, an attempt at whole-body counting was considered justified.

Ten metric tons of sugar were obtained from the Brazilian Institute of Sugar and Alcohol and half a ton of iron from the National Steel Co. as shielding material. The chemical purity of sugar and its low price make it an ideal shield. As shield thickness increases, however, the volume and mass grow disproportionately. A compromise was sought using the principles of the shadow shield.

The 166 sacks of sugar, each 60 kg, were arranged in the form of a bowl to give the equivalent of 6 in. iron shielding below the subject and 4 in. on the sides. Above the cave a shield of 3 × 3 in. iron bars was used together with 2 in.

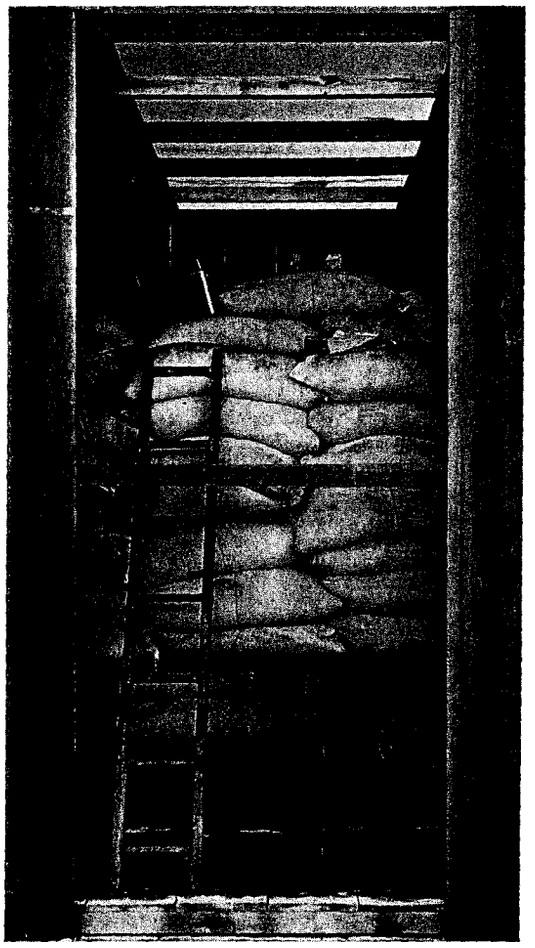

FIG. 2. View of sugar shield for whole-body counter.

Table 4. Body Burdens Measured by Whole-body Counting

Subject	Sex	Age	Occupation	Mibra*	^{224}Ra (nCi)	^{226}Ra (nCi)
A	F	47	Housewife	—	5.5	5.0
B	M	50	Owns bar	25	5.1	N.D.
N	M	39	Fisherman	6	5.1	12.5
O	M	41	Owns Bar	12	3.3	N.D.

* Mibra: Years of work in monazite separation plant. Plant closed December 1963.
Note: Subjects A and B are listed under the same letters in Table 3.

of lead. The shield and detector were housed in a wooden shack in the veranda under the University building. The building added 1.3 m of concrete to the shielding. A picture of the whole-body counter is given in Fig. 2.

A 4 × 4 in. Na (Tl) well-type crystal, integrally mounted to a phototube was used. A small reamplifier sent the pulses through a cable to the fifth floor laboratory where the counts were registered by a Nuclear Data 256 channel analyzer.

The background index, defined here as the total counting rate from 0.4 to 2.0 MeV divided by the volume of the crystal, was found to be 0.92 cpm/cc. This was considered reasonably good for a provisional counter.

The counter was calibrated with standard solutions of ^{226}Ra and ^{228}Ra. The solutions were sandwiched between two 4 in. thick plastic bottles filled with distilled water to represent a phantom of the chest region.

The standard error in the calibration experiments can be used to estimate a lower limit of sensitivity. Defining the Minimum Detectable Amount as twice the standard error, the M.D.A. for ^{224}Ra is 1.2 nCi and for ^{226}Ra 1.8 nCi.

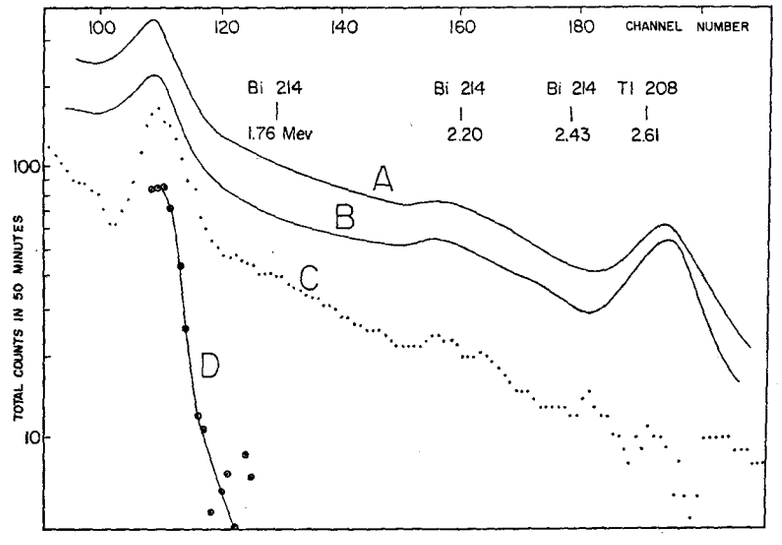

FIG. 3. Whole-body counting spectra. A. Ten Guarapari subjects with background. B. Background. C. Ten Guarapari subjects minus background. D. Ten Rio de Janeiro subjects minus background.

In a provisional set up it is impossible to hold error to a minimum. It is necessary to assess them carefully, especially the systematic errors. Among the smaller errors are temperature change and the subsequent gain shift in the phototube leveling off the peaks of some channels. Another is the variation of the natural background in the well ventillated shack.

Among the two major sources of error is what can be called partial body counting. To lower the background iron bars were closed in tightly about the crystal reducing the cone of sensitivity. Head, shoulders and at least the upper part of the lungs were not within the sensitive cone. The ^{40}K peak was studied to estimate the fraction of the body counted. Assuming normal potassium content, the conclusion is reached that less than a fourth of the body was counted.

The second major source of error was noise captured by the cable. This was studied separately with the phototube voltage off and amounted to approximately 30% of the background in the channels of interest. The error rests in this, that noise is not constant.

Eleven individuals came from Guarapari to be counted. Ten subjects from Rio de Janeiro were also counted. More than a score of background measurements were taken. For each channel in the spectrum the counts from ten subjects from Guarapari were averaged. The same was done with ten backgrounds and ten subjects from Rio de Janeiro. The graph of these averages is given in Fig. 3. The activity of the Guarapari people seemed to be high enough to pass from the idea of population sample to make cautious statements about individuals.

But the sensitivity of a whole-body counter depends less on the background than on the stability of the background. If the ten Rio de Janeiro subjects are accepted as background all the Guarapari subjects have body burdens of ^{224}Ra from 0.5 to 10 nCi. But the noise in the cable varies too much for us to assume that the background of one week is equal to that of another.

Accepting the spectrum with the highest noise level in the three weeks of operation as the background, the body burden for three Guarapari subjects is given in Table 4. The energy regions for ^{214}Bi have been chosen from 1.575 to 1.860 MeV and for the ^{208}Tl peak from 2.575 to 2.730 MeV. The suggestion of peaks in these regions of interest confirms the conclusion of the presence of internal contamination. Four other people appear to have measurable body burdens, but nothing can be said with confidence because they are below the M.D.A.

Nothing is known about the origin of the body burden and, for the present, it is assumed that intimate contact with surface contamination and dust in the air is the source. For this reason the data is given for ^{224}Ra.

One of the subjects mentioned in Table 4, A, is known to have chromosomal aberrations. It is believed that the continuation of this research project can shed light on the biological consequences of chronic exposure to low level radiation.

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