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STUDIES ON THE NATURAL BACKGROUND RADIATION IN ITALY

A. CARDINALE, L. FRITTELLI and G. LEMBO
Servizio di Fisica Sanitaria, CSN-Casaccia, CNEN, Rome
and
F. GERA and O. ILARI
Divisione Protezione Sanitaria e Controlli, CNEN, Rome

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Abstract—The exposure rate due to the gamma-ray natural background in some representative areas of the Country was studied by means of a portable high-pressure ionization chamber. In a limited area such study was integrated by a survey on the quality of background radiation, carried out by gamma spectrometric measurements.

The spectrometric study permitted the determination of the contributions to the total by the individual natural radioactive series and by cosmic rays, while the ionometric method measured the total values of the gamma exposure.

The measurement areas were chosen on the basis of joint geological and demographical considerations: they are, in fact, representative of the main geological formations, preferentially chosen in the parts of the peninsula characterized by a significant population density.

The results of the measurements are therefore indicative of the maximum range of gamma exposure to which the Italian population is subjected from natural causes.

This range appears to be rather wide, in close correlation with the geologic features of the soil, the values of exposure rate ranging from a few μR/hr on the alluvia up to 50–60 μR/hr on the volcanic rocks.

The authors also measured the exposure rate due to gamma-ray background in a large city, as an introduction to a future investigation of the contribution to the exposure rate by the building materials of roads and houses.

INTRODUCTION

THE IMPORTANCE of knowing radiation of natural origin lies in the fact that mankind has always been exposed to natural background radiation at relatively stable dose levels, so that the doses due to that source can be used as a standard of reference to those due to radiation from artificial sources.[1]

Natural radiation is due, as is known, to two causes: cosmic rays and naturally occurring radionuclides; the latter give rise not only to external radiation, but also to internal radiation by intake in the body.

As for cosmic rays, the dose due to the ionizing component, chiefly formed by muons, changes little with latitude, in the order of 10% from the equator to the geomagnetic poles. The neutronic component is more influenced by the latitude effect; in fact, the relevant dose absorbed decreases by 30% passing from the poles to the equator.[1] Altitude also influences rather remarkably the exposure rate due to cosmic rays, which doubles in value, approximately every 1500 m, with the increase of altitude from sea level up to several kilometers.

When radiation is of terrestrial origin, the content of radioactive substances in the soil and in the rocks is greatly different from place to place, especially in regard to the geological features of the different areas.

In order to obtain a sufficiently accurate evaluation of the average radiation in human population due to natural causes, it is therefore necessary to collect as much data as possible on natural background radiation, and every contribution in this sense is considered very helpful.

This scheme is sponsored by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), that collects and publishes periodically in its reports[1–3] the data on radiation and natural radioactivity of human environment, co-ordinating and indicating the most trustworthy values for the average dose to the human population due to different natural sources. Such values, at the present state of knowledge, are those shown in Table 1, taken from the UNSCEAR report.[1]

Table 1. *Mean doses absorbed yearly from natural sources in "normal" areas of the Earth*

Source	mrad/yr Gonads	mrad/yr Bone marrow
External irradiation		
(1) Cosmic rays		
(a) ionizing component	28 *	28 *
(b) neutrons	0.7*	0.7*
(2) Terrestrial radiation	50	50
Internal irradiation		
^{40}K	20	15
^{87}Rb	0.3	0.3
^{14}C	0.7	1.6
^{226}Ra	—	0.03
^{228}Ra	—	0.03
^{210}Po	0.3	0.3
TOTAL	100	96

* The values for cosmic rays are referred to the sea level and mean altitudes.

Within this international interest in the problems of natural radiation, the authors of this report have carried out a programme of studies on background radiation, both in regard to the techniques and methods of measurements and to the quantitative and qualitative aspects that it presents in Italy.

This report presents the results of a number of preliminary studies aimed at obtaining a first summary estimate of the spectrum of the dose values to which the Italian population is exposed through external radiation of natural origin. These results have been obtained by ionometric measurements, checked, in some cases, by gamma spectrometric measurements.

MEASUREMENTS PLANNING CRITERIA

The most suitable standard to obtain information about the maximum range of background radiation values appeared to be that of selecting, by an accurate study of the geological maps of Italy, those places whose geological features were such as to anticipate the presence of very high or very low contents of natural radioactive substances (neglecting particular areas characterized by mineralizations of radioactive substances).

The measurements of gamma exposure rate in the air above such soils should give information about the lowest and highest dose values obtainable in the Country.

Examples of applications of such criterion are represented by the measurements made on the volcanites of Cimini mountains in Latium, on the syenites of Biella in Piedmont, on the ophiolites of Impruneta in Tuscany, and, lastly, on the limestones of Simbruini mountains in Latium.

On the other hand, considering that the interest of the present work is the irradiation of the population, another relevant piece of information concerns the exposure levels of significant groups of population. For this purpose, measurements of gamma exposure rate were made also in connection to geological formations not characterized by extreme contents of radioactive substances, but largely spread over the Italian territory or present in areas with high population density.

Examples of application of the latter principle are represented by the measurements made on arenaceous or argillaceous formations in the Tusco–Emilian Appennine and on the slopes of the Sila mountains, as well as in Po valley, in the Tiber valley and in the Pianura Campana, all these being alluvial plains of the recent Quaternary. Moreover, these plains are characterized by a population density among the highest in Italy (from 300 to 1000 per km²).

Ultimately, in order to obtain, even in a preliminary way, a wider picture of the population exposure to external radiation due to natural sources, levels of gamma exposure rate were examined in an environment of a large city, where a substantial fraction of the population lives and where radiation is due not so much to the geological characteristics of the area, as to those of the materials used in the building of the streets and houses.

To this end many measurements of gamma exposure rate were made in spots representative of the different components of the city chosen

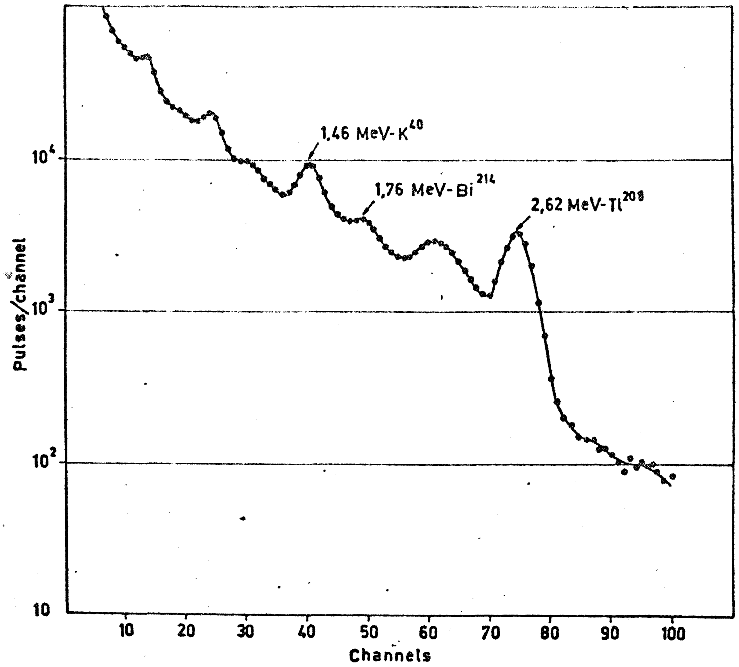

FIG. 2. A typical gamma-ray spectrum of background radiation.

(streets pavements, squares, gardens, buildings, houses), distributed uniformly through the city itself.

MEASURING INSTRUMENTS AND METHODS

The measuring instrument used for ionometric measurements of the exposure rate consists of a 45 atmospheres ionization chamber coupled with a simple electrometric circuit.[4] From this instrument undoubted practical advantages derive, since it is supplied by accumulator batteries, is light and easily used and has a high sensitivity down to 1 μrad/hr.

In some cases, the ionometric measurements were accompanied by spectrometric measurements, in order to analyse separately the contributions to the gamma exposure rate in the air due to each radioactive element present in the ground and to cosmic rays. The instrumentation used for these measurements was a 3 × 3 in. NaI (Tl) scintillation detector and a multi-channel analyzer; powered by an electric generator in the fields (Fig. 1).

The method used for the spectrometric data calculation of the exposure rate due to each component is the one developed by BECK et al.[5] Some improvements were applied to it, especially in the exactness of calibration factors and of measurement itself.

Assuming that natural radionuclides (^{40}K, ^{238}U series, ^{232}Th series) are distributed uniformly in the ground and form an infinite half-space source, and further, that there exist equilibrium conditions for natural series, it is possible to determine for each series a calibration factor A/I (photopeak area A corresponding to unit exposure rate I) that allows calculation of the exposure rate due to each series, by measuring the area of photoelectric peak for a line which is characteristic for that series. Considering a typical background spectrum (Fig. 2), three peaks can be distinguished in particular: the 1.46 MeV for the ^{40}K; the 1.76 MeV for the Uranium series; and the 2.62 MeV for the Thorium series. For these three peaks the above mentioned calibration factor A/I was determined using more sophisticated methods of calculation to improve the accuracy of the results.[6–8] The values of A/I employed for the three series are reported in Table 2.

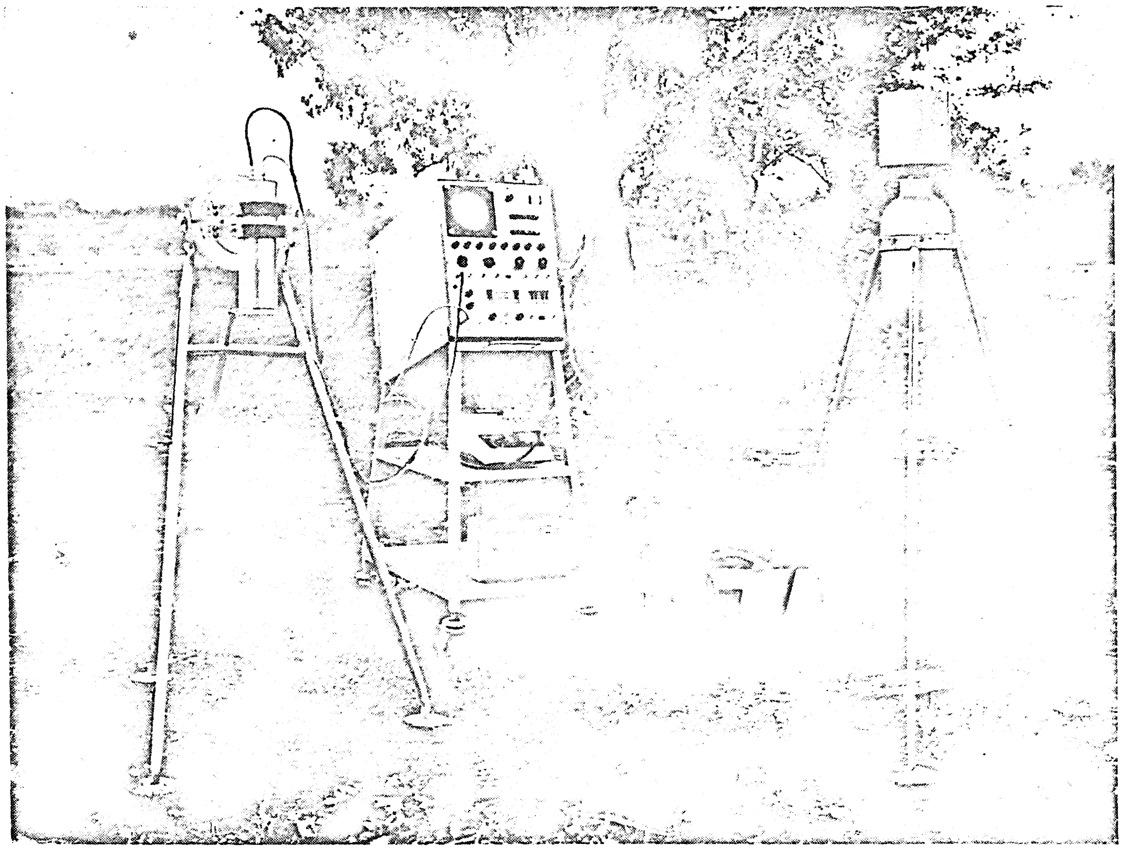

FIG. 1. Instrumentation used for the measurements of gamma-ray background radiation

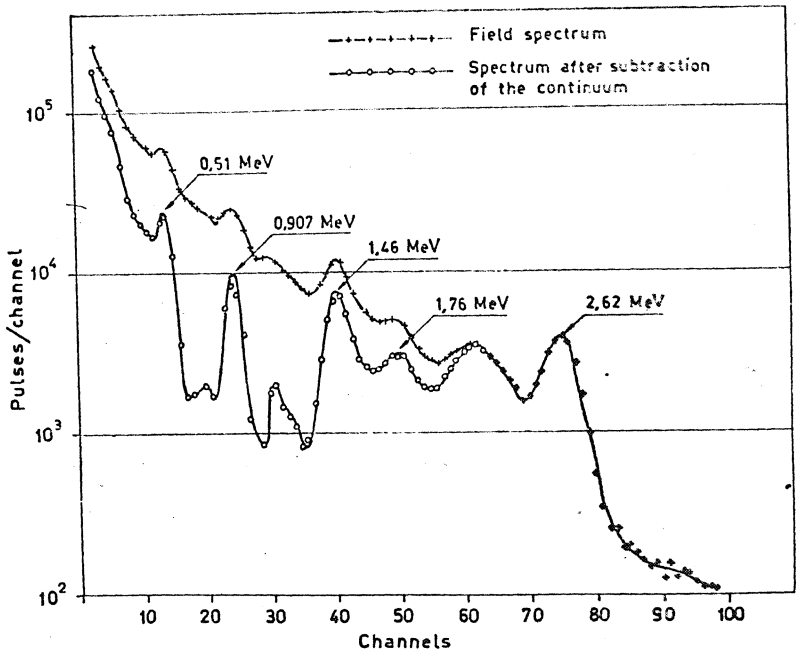

FIG. 3. Subtraction of the continuum from a background gamma-ray spectrum.

Table 2. Values of calibration factor A/I for natural radionuclides in the ground

Characteristic peak energy (MeV)	Radionuclide	A/I $\left(\frac{\text{c.p.s.}}{\mu\text{rad/hr}}\right)$
1.46	^{40}K	5.8 ± 0.2
1.76	Uranium	1.13 ± 0.03
2.62	Thorium	0.82 ± 0.02

Furthermore, a computer program for the calculation of the peak area for background spectra was formulated, taking into account that the particular geometry of the source did not allow us to use the usual least squares method, utilizing spectra of monochromatic sources of a known activity as input functions. This programme allows, for each spectrum, the determination of the continuum through a fit by a linear combination of two exponentials on the basis of the counts obtained for each channel.

This curve which represents the continuum is shifted downward so as to be tangential to the spectrum and subtracted channel by channel from the spectrum itself. The resulting spectrum is shown in Fig. 3. It is considered a superimposition of gaussian curves, one for each peak, that might be determined using a suitable "best-fit". The areas of these gaussians are then calculated.

As for the contribution of cosmic rays, it was determined by ionometric and spectrometric measurements made over water (in this particular instance, a lake) so that the contribution to exposure rate in the air due to natural radionuclides should be negligible.

The measurements made over the lake showed that, out of a total value of exposure rate of 4.6 μR/hr, measured by ionization chamber, only 0.3 μR/hr determined by spectrometric measurement, were to be attributed to terrestrial radiation, whereas the remaining 4.3 μR/hr represented the contribution of cosmic radiation.

The value obtained for the contribution of cosmic rays is in accordance with the results presented in the literature, if we consider the effects of altitude and longitude: the mean value would be 4.2 μR/hr at a height of 500 m, exactly where the lake in question is situated.

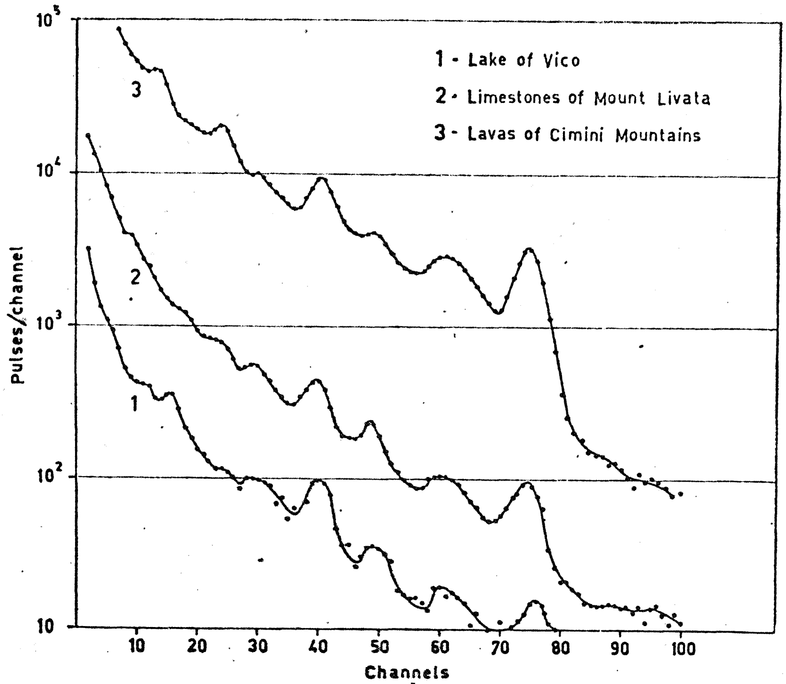

FIG. 4. Geographical distribution of measurement areas.

SPECTROMETRIC MEASUREMENTS IN LATIUM

In certain areas where the ionometric measurements were made, [Cimini mountains, Tiber valley, Mt. Livata, all in Latium] the results were verified and analyzed in detail by spectrometric measurements.

Figure 4 shows examples of gamma spectra obtained in areas with different levels of exposure rate and normalized to the same measurement time-length.

The lower spectrum (No. 1) was obtained at 1 m above the level of the lake of Vico, at the centre of the lake, and corresponds to a value of exposure rate of 0.3 μR/hr, apart from cosmic rays. The intermediate spectrum (No. 2) regards a measurement over calcareous emergences present on Mount Livata at the altitude of 1350 m. The background levels are low, but, contrary to the norm of background spectra, the 1.76 MeV peak of the Uranium series is most evident, showing a greater relative abundance of Uranium in comparison with the other natural radionuclides in the ground in question.

Spectrum No. 3 shows a measurement made over a soil constituted primarily of crushed lavic material, in the area of Cimini mountains, near the lake of Vico. In this instance, the contribution of the Thorium family proves very important.

The main results obtained by the spectrometric method are reported in Table 3, together with the data of the ionization chamber. From the last two columns of the table, it can be observed that there is a satisfactory correspondence between the results obtained by the two methods of measurement. Some excessive differences between the values shown in the fourth line, are attributed to the hypotheses concerning the geometry of the source, as they had been assumed in the calibration of the spectrometer in terms of exposure rate. Then the most reliable value should be the one supplied by the ionization chamber, that allows exposure rate measurements also where the geometry of natural sources cannot be likened to an infinite half-space.

Moreover, from Table 3 it can be seen that the range of the exposure rate measured is between 1 μR/hr and 55 μR/hr.

Table 3. Comparison of gamma-ray background exposure rates determined by different instruments and methods

Areas of measurements (See Fig. 5)		Nature of ground	Altitude (m)	Gamma exposure rate (μrad/hr) Gamma spectrometry: Cosmic rays	K	U	Th	Total intensity	Ionization chamber (Total intensity)
n. 5	Cimini mountains	Meadow	700	5.1	2.7	10.8	14.1	27.6	27.8
n. 5		Lavic emergence	700	5.1	5.8	26.6	34.4	66.8	54.0
n. 5		Meadow	520	4.5	1.4	6.8	6.8	15.0	14.6
n. 5		Lavic pavement	550	4.6	4.1	4.3	14.9	23.3	32.6
n. 5		Lavic gravel	540	4.6	5.0	13.9	26.9	45.8	45.2
n. 5		Meadow	540	4.6	3.9	10.9	19.6	34.4	36.6
n. 6	Tiber valley	Meadow	23	3.6	0.6	2.4	3.0	6.0	6.0
n. 7	Mount Livata	Red earth	1350	6.6	0.8	1.6	3.6	6.0	7.4
n. 7		Meadow	1350	6.6	1.1	3.8	4.2	9.1	8.8
n. 7		Limestone	1350	6.6	0.2	0.8	0.6	1.6	1.7

MEASUREMENTS OF GAMMA EXPOSURE RATE THROUGH ITALY

Information on the maximum range of the dose values absorbed by the Italian population through gamma external irradiation were obtained, by making a number of measurements of gamma exposure rate by the ionization chamber previously described.

The measurements were carried out in 11 particular areas of the country, selected according to geologicodemographical principles. The geographical distribution of these areas is shown in Fig. 5.

During the whole survey particular care was given to choosing the best conditions of geometry, making measurements in areas with surfaces as sufficiently flat as possible and avoiding the vicinity of rocky hill-sides, buildings and other significant obstacles. Generally this aim was achieved, but in some circumstances, especially in mountainous areas, it was necessary to make measurements in poor conditions of geometry, getting results necessarily affected by a greater error than in the other cases.

Another difficulty that sometimes prevented ideal measurement conditions, especially in flat areas, was difficulty in finding spots where the characteristic unaltered rock of the area emerged. In these cases the measurements concerned the agricultural soil, with all the procedures of alteration more or less advanced which have irreparably modified the original chemism of the soil.

The geological characteristics of the eleven areas where the measurements were made will be briefly analyzed, described along with the radiation levels found in them.

Area No. 1 is in Piedmont, near Biella, within the area of emergence of syenitic batholith of Biella. It consists of a remarkable intrusive mass, mainly composed of a normal syenite of the alkalic-calcic series.[9] It has a medium grained granite-like structure, and among the accessory minerals there is predominantly apatite, with lesser amounts of titanite and zircon. Among the rarest accessory minerals, inclusions attributed to fergusonite and uranite are present which are characterized by very high specific activity.

Spectrometric measurements were not made in this area, but from the literature the activity of these rocks is due primarily to radionuclides of the Uranium series.

The values of the exposure rate measured in connection with the emergences of the unaltered rock are 26 and 33 μR/hr. These values, and all those mentioned in the geological description do not include the contribution due to cosmic rays.

The second series of measurements (area No. 2) was carried out in the Po valley, a little north

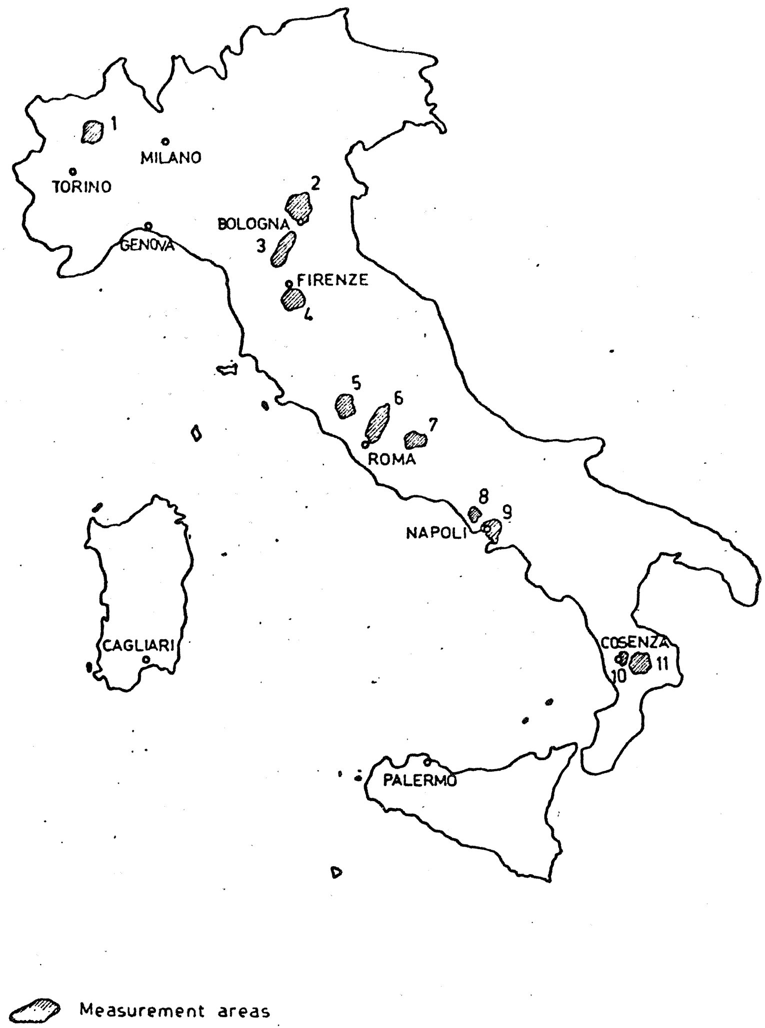

FIG. 5. Geographical distribution of background exposure rates related to the ground nature in the areas examined.

of Bologna, over an agricultural soil formed from alluvia of the Recent Quaternary. The area is quite flat and intensively cultivated.

As was expected, the values of the exposure rate were rather low, being within 5 and 6 μR/hr.

Area No. 3 is situated on the Tusco–Emilian Appennine. Measurements were affected in different places by emergences of clastic sediments, such as clayey sands of the medium–superior Pliocene, Scaly Clay and Macigno (a sandstone of compact texture quartzy-micaceous with plentiful feldspars, deriving from acid and alkaline crystalline rocks).

The values found are in accordance with what is known of the low radioactivity of sedimentary materials, ranging from 5 to 7 μR/hr.

South of Florence, in area No. 4, the absolute minimums of gamma exposure rate were measured. In that area there exist some emergences of ophiolite: the content in radioactive substances of this rock is exceptionally low, and it may be explained considering the intense secondary processes that the intrusive rocks of ophiolitiferous formation have undergone. In fact, during the serpentinization process that the originary basic intrusive rocks, already poor in radioactive substances, have gone through, it is likely that they were leached with a consequent reduction of the radioactive substances of the rock.

Consequently the radiation levels above those rocks are less than 1 μR/hr.

The maximum values of gamma exposure rate were found in area No. 5. Area 5 is an area where volcanic rocks of Cimini mountains, in Latium, north of Rome, emerge.[10,11] The values of the exposure rate vary from 15 to 54 μR/hr.

The remarkable variability of the values measured depends on the variability of the types of soils over which the measurements were made. The highest values, up to 54 μR/hr, are found at lava emergences of the volcano of Vico, whereas the lowest values of exposure rate were found above the agricultural soils in the flat area north of the lake of Vico, within the belt of the caldera. These are alluvial materials formed entirely at the expense of the surrounding volcanic rocks; the mechanisms of erosion, transport and sedimentation have reduced their radioactive substances.

The spectrometric measurements made in the field showed that the principal contribution to natural radiation in this area is due to the dominant presence of radionuclides of the Thorium series, that are responsible for over 50% of the total exposure rate.

According to MARINELLI and MITTEMPERGHER[12,13] the causes of the richness in Thorium of the volcanites of Cimini mountains, and in particular of the lava-rocks of the volcano of Vico, are to be found in the origin of the magma and in the complex processes of differentiation that these magmata have undergone. In fact, these vulcanites are rich in numerous pneumatophilous elements, besides Thorium.

The measurements of area No. 6, in the Tiber valley, were made over agricultural soils formed at the expense of recent alluvial materials. The exposure rate 6 μR/hr, turned out to be of the same order as that found over the alluvial plains of the Po valley.

Area No. 7 is situated in the Simbruini mountains, in Latium, east of Rome, where they emerge over a considerable extension of mesozoic limestones. On Mount Livata, plains situated at altitude between 1300 and 1600 m above sea level, limestones present typical forms of Karst erosion.

Some measurements made at emergences of compact limestone indicated a total exposure rat of about 1.5 μR/hr of which about 50% was due to the contribution of the Uranium series and 35–40% to that of the Thorium series, as shown by spectrometric measurements.

At a short distance from the limestone emergences, over a terrain apparently formed from the undissolvable residue of the chemical dissolution of limestone, the exposure rate measured is distinctly higher, about 7–8 μR/hr. In this case the contribution of Thorium is prevalent over that of Uranium; this is explicable by the lower solubility of Thorium to that of Uranium, which causes its enrichment in the insoluble residue.

Area No. 8 is situated in the alluvial plain of the Volturno river. Also in this case alluvia of the Recent Quaternary are involved; the exposure rate recorded there is about 12 μR/hr. This high value is explained by the fact that alluvia have been formed in part at the expense of volcanic materials of Campanian Apparatuses that emerge in the catchment basin of the Volturno river.

At a few kilometres distance, in area No. 9, the measurements were made at the emergences of the vulcanites of the Campanian Apparatuses.

Again rather high exposure rate values are found, even though not so high as those recorded on Cimini mountains. The values measured range from 17 to 26 μR/hr; the highest exposure rate was measured over the lavas of Vesuvium, whereas lower values were found in correspondence with the emergences of tuffs of Mount Somma and of Campi Flegrei.

Areas 10 and 11 are in Calabria.

Area No. 10 is situated at the foot of the mountainous chain of Sila, near Cosenza; it is characterized by the presence of sandstones and sands of Pliocene with rather modest radiation levels, of the order of 7 μR/hr.

Area No. 11 is situated on metamorphic materials and granites emerging in the massif of Sila. The measurements of exposure rate in this case gave results not agreeing with the expectations based on the lithological features. The values measured, from 3 to 9 μR/hr, are

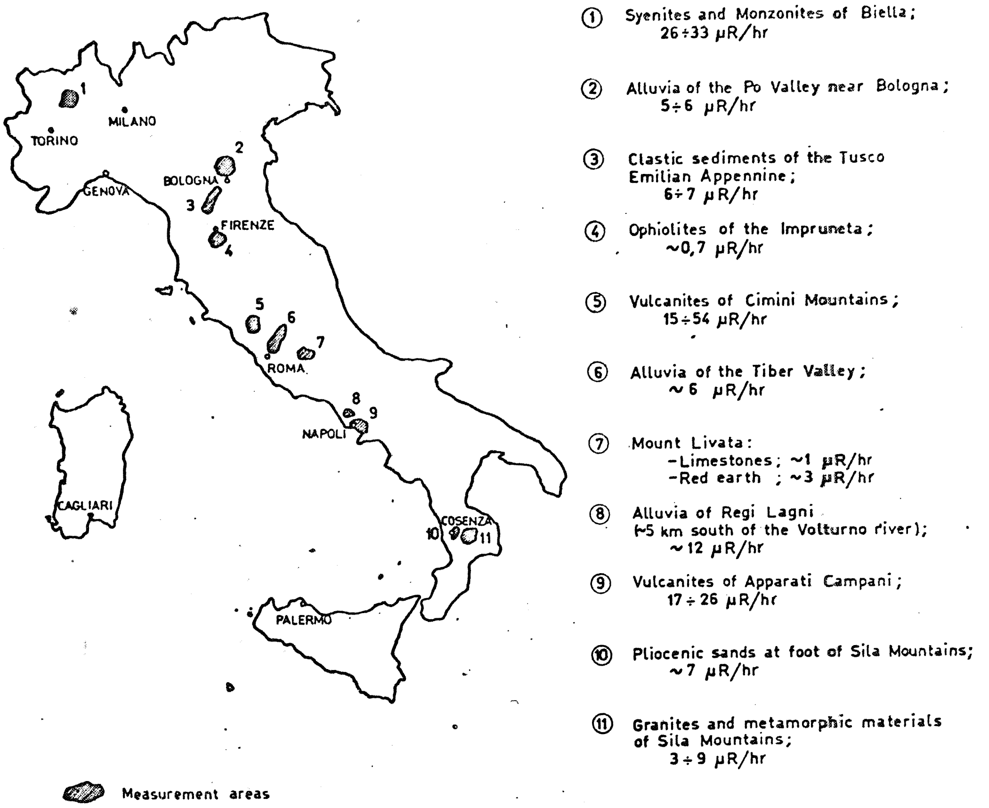

FIG. 6. Distribution of the frequencies of the exposure rates related to the geological characteristics of the ground.

not very high in comparison with the amount commonly measured in other metamorphic formations and acid intrusions.

The above data are presented in a resumptive form in Fig. 6, where the principal lithological features and the intervals of the values of gamma exposure rate are indicated.

Figure 7 shows a representation of the distribution of the values of exposure rate in relation to the geological features of the soils, reduced to a scheme of four fundamental categories of rocks. It can clearly be seen, confirming the results obtained by other authors[14–17], that the lowest exposure rates are associated with sedimentary and metamorphic rocks, while effusive rocks are characterized by very variable, but generally higher radiation levels. Intrusive rocks generally show high exposure rates, with the only exception being the granites of Sila, where further investigation is warranted.

MEASUREMENTS INSIDE ROME

The preliminary study of background radiation in Italy was completed by a number of measurements made in Rome in places representative of various environments of the city [streets, squares, public gardens, and inside a number of houses] to get a measure of the gamm-ray exposure due to the presence of building materials.

The survey was carried out by measuring the exposure rate by ionization chambers in about 80 spots outdoors and inside 15 private houses, taking care to distribute the measurement points as uniformly as possible within the city. Suburban quarters were excluded, such as

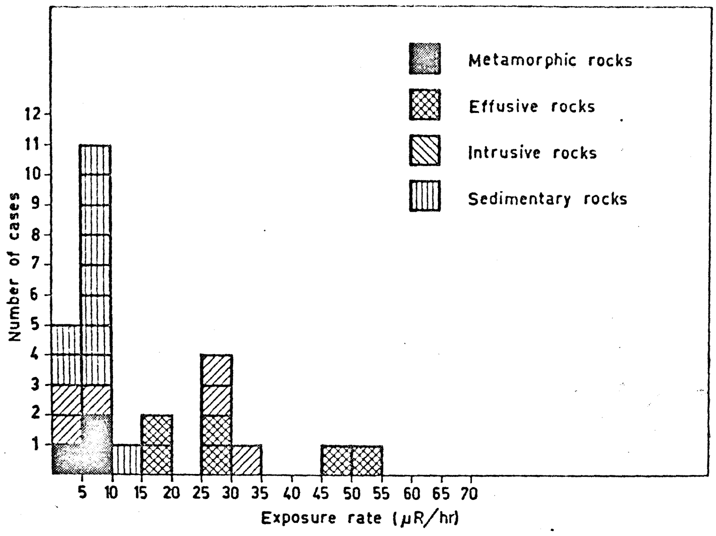

FIG. 7. Comparison between background gamma-ray spectra regarding different measurement sites.

EUR, the Tomb of Nero, Centocelle, Cinecittà, etc.

The results of the measurements are presented in Fig. 8 in the form of histograms of the distribution of the values found (1) in the whole city, excluding houses, (2) in the houses, and (3) in the three groups of different environments where it was deemed opportune to subdivide the city on the basis of the differences of paving materials.

As expected, the lowest value of the exposure rate is found again in areas without paving, such as public gardens (19.7 μR/hr). In fact, street paving is effected with materials of local supply, which, in Rome district, are prevalently of lavic nature and therefore with high contents of radioactivity. Furthermore, the bituminous mixtures employed in the paving are normally very rich in Uranium: that is due to the phenomena of Uranium concentration in organic materials that are at the base of the prehistoric origin of oil, of which bitumen is a by-product. This explains the relatively high value of the exposure rate above road-beds.

Pavements represent an intermediate case, in the sense that the materials used for their paving are generally the same as those used for the streets, but with thickness extremely reduced, and, besides that, they are without foundation, which, in Rome district, is also formed by lavic rocks and pozzolana.

As regards the houses, the number of cases observed is rather small, but permits to observe, in any case, that the values are almost uniformly distributed within a wide interval from 12 μR/hr to 30 μR/hr, which may be explained by the different periods of building of the houses examined. Corresponding to differences in structural techniques and in the building materials employed.

CONCLUSIONS

To conclude, even though the number of data available is rather scanty, it seems, however, possible to try a preliminary estimate of the interval of dose values to which the Italian population may be exposed from gamma-ray natural background. In this case the doses are expressed in mrad/yr and were calculated at the level of the gonads and bone marrow, applying the attenuation factors for the dose absorbed in these organs reported in the literature.[18]

A similar calculation was made for the mean dose to the population of the city of Rome, determining the weighted mean between the values measured in the open and in the houses,

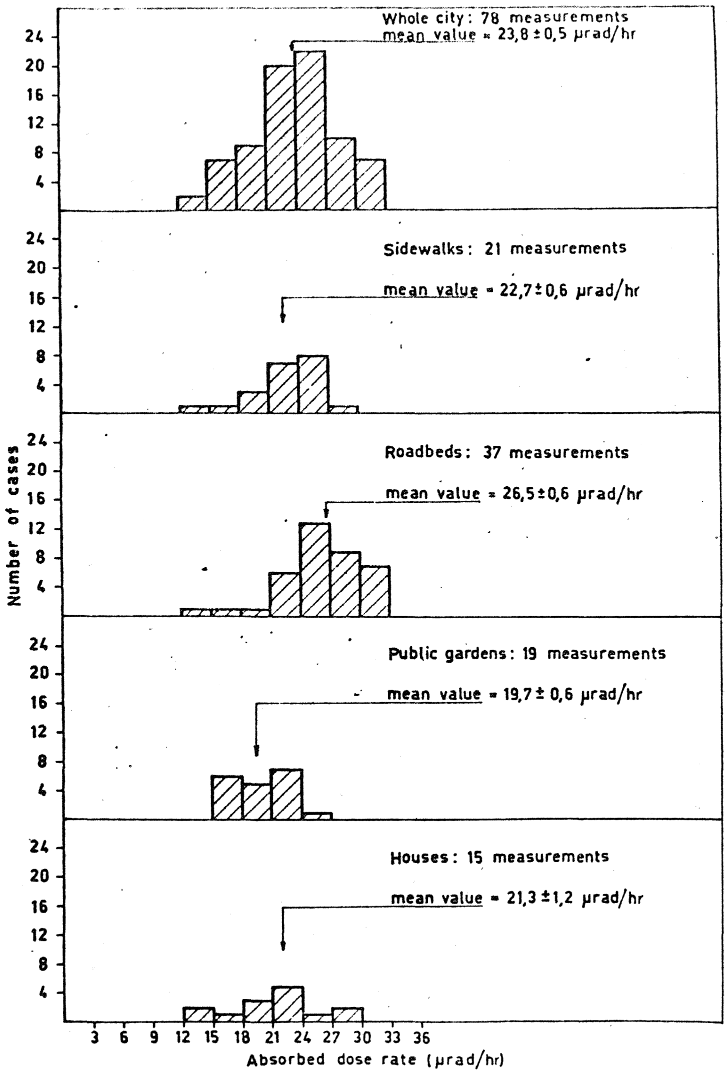

FIG. 8. Histograms of the distributions of the values of the absorbed dose rate related to the city of Rome.

Table 4. Mean annual doses from gamma-ray background compared with the UNSCEAR values

Area	Annual dose (mrad/yr)		
	Air	Gonads	Bone marrow
Italy (min.)	12	7	8
Italy (max.)	475	300	310
Rome (average)	203	128	132
UNSCEAR	122	77	79

on the basis of a mean permanence of 18 hr/day indoor and 6 hr/day outdoor.

Observing all these data in Table 4, it can be noted that they are often rather high, especially if compared with the values assumed by the United Nations Scientific Committee as mean doses to the human population from gamma external irradiation from natural sources.

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1. *UNSCEAR Report*, Suppl. n. 14 (A/6314) (1966).
2. *UNSCEAR Report*, Suppl. n. 16 (A/5216) (1962).