VOL. I PART I

SELECTED SCIENTIFIC PAPERS

FROM THE

ISTITUTO SUPERIORE DI SANITÀ

ROMA: FONDAZIONE EMANUELE PATERNÒ
VIALE REGINA ELENA, 299 - ANNO 1956

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ALCHEMISTS MELTING CRUCIBLE SURROUNDED BY BURNING COAL
FROM AN OLD ITALIAN M. S. (1464)

CONTENTS

1. M. AGENO, G. CORTELLESSA and R. QUERZOLI — **The low energy gamma ray spectrum of cosmic radiation.**

Summary. — The energy spectrum of the ultra-soft component of cosmic radiation was studied with a single-channel scintillation spectrometer with one sodium iodide crystal in the open air (at sea level) and below about 100 g cm^{-2}. It was found that this component consists substantially of secondary photons, the majority of which have an energy of between 50 and 200 keV. The band has a very well-defined maximum at about 80 keV in the open air and about 90 keV below 100 g cm^{-2}. The intensity incident in the open air was roughly estimated at 100 quanta per min. per cm^2 sterad. about the vertical. On the hypothesis (which is true as a first approximation) that the incident radiation is isotropic, this corresponds to an energy flux of about 1 per cent. of the total cosmic radiation energy incident on the surface of the earth.

The discontinuity of absorption on both sides of the K limit in lead absorption measurements confirms the photon nature of the ultra-soft component.

Riassunto. — Con uno spettrometro a scintillazione ad un canale, munito di un cristallo di ioduro di sodio, si studia lo spettro energetico della componente ultra-molle della radiazione cosmica, all'aperto (al livello del mare) e sotto circa 10 g cm^{-2}. Si trova che tale componente è sostanzialmente costituita da fotoni secondari per la maggior parte di energia compresa tra 50 e 200 keV. La banda ha un massimo molto marcato attorno a 80 keV all'aperto e a 90 keV sotto 100 g cm^{-2}. La intensità incidente all'aperto viene valutata grossolanamente a 100 quanti al minuto, per centimetro quadrato e steradiante attorno alla verticale. Ciò corrisponde nell'ipotesi (vera in prima approssimazione) che la radiazione incidente sia isotropa, a un flusso di energia pari all'1% circa dell'energia totale incidente sulla superficie del suolo per effetto della radiazione cosmica.

Mediante misure di assorbimento in piombo, si conferma la natura fotonica della componente ultra-molle, mettendo in evidenza la discontinuità dell'assorbimento ai due lati del limite K di questo elemento.

Résumé. — Avec un spectrométre à scintillations à un seul canal, muni d'un cristal d'iodure de soude, on observe le spectre énergétique de la composante ultra-molle de la radiation cosmique, à ciel ouvert (au niveau de la mer) et sous environ 100 g cm^{-2}. On trouve alors que cette

composante est en substance constituée par des photons secondaires pour la plupart d'une énergie comprise entre 50 et 200 keV. La bande a un maximum très marqué autour de 80 keV à ciel ouvert et de 90 keV sous 100 g cm^{-2}. L'intensité incidente à ciel ouvert est évaluée grosso modo à 100 quanta par minute, par centimètre carré et sterad. autour de la verticale. Dans l'hypothèse (vraie en première approximation) que la radiation incidente soit isotrope, cela correspond à un flux d'énergie égal à 1 pour cent environ de l'énergie totale incidente sur la surface du sol par l'effet de la radiation cosmique.

Moyennant des mésures d'absorption en plomb, on a la confirmation que la composante ultra-molle est formée par des photons, en mettant en évidence la discontinuité de l'absorption sur les deux côtés de la limite K de cet élément.

Zusammenfassung. — Mit einem einkanaligen Szintillationsspektrometer, das mit einem Natriumjodid-Kristall versehen ist, wird das energitische Spektrum der überweichen Komponenten der kosmischen Strahlung im Freien (auf Meereshöhe) und bei etwa 100 g cm^{-2} untersucht. Hierbei wird gefunden, dass diese Komponente hauptsächlich aus Sekundärphotonen besteht, die ihrerseits wieder eine Energie zwischen 50 und 200 keV haben. Das Band hat ein sehr ausgesprochenes Maximum bei 80 keV im Freien und bei 90 keV bei 100 g cm^{-2}. Die einfallende Intensität im Freien wird auf ungefähr 100 Quanten pro Minute pro Quadratzentimeter und Sterad. um die Senkrechte angesehen. Unter der Voraussetzung (die annäherungsweise richtig ist), dass die einfallende Strahlung isotrop ist, bedeutet dies einen Energiestrom, der etwa 1% der auf die Bodenfläche infolge kosmischer Strahlung einfallenden Gesamtenergie entspricht.

Durch Messung der Absorbierung in Blei wird die photonische Natur der überweichen Komponente bestätigt, wobei die Unterbrechung der Absorbierung zu beiden Seiten der Grenze K dieses Elements deutlich wird.

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1. *Introduction.*

It has been known for several years that at sea level a fairly large number of electrons and photons of very low energy are present in cosmic radiation. These are usually interpreted as the final products of energy degradation of the electromagnetic component in the atmosphere.

Scant attention has been paid up to the present to this radiation of very small penetrating power. There are two reasons for this neglect: first, such radiation has too little energy to overcome the « cut-off » given by the walls of counters, and is thus unable to activate normal detection apparatus; and secondly, there is a complete failure at such low energies of the methods which have been used for the complete development of the theory of multiplicative showers at high energies, with the result that below a few MeV the structure of the electromagnetic component has been impossible to predict even by calculation.

All that has been known about the phenomenon up to the present can be summarized in a few words. Schönberg (1) was the first to note the existence of considerable divergences between intensity measurements of cosmic radiation carried out at high altitudes by means of counters in coincidence and measurements carried out in ionization chambers. It is suggested that the explanation of the divergence is the existence of a fairly soft component which is to some extent able to penetrate the single wall of an ionization chamber, but not the numerous walls of a series of counters in coincidence.

Experimental evidence at sea level for the effective existence of this ultra-soft radiation was next obtained by Bernardini & Ferretti (2,3); they used a system of counters in coincidence in which the particles had to be capable of penetrating at least 3 mm of aluminium in order to be detected. They studied the absorption of this radiation by a few mm of lead or brass and the generation of secondary electrons in the same screens, and reached the following conclusions:

a) There does exist a fairly intense ultra-soft component in cosmic radiation. It consists of electrons and photons. 10 per cent. of the total radiation is absorbed by 2 mm of lead and 20 per cent. by 4 mm of lead: 8 mm of lead absorb practically the same as 4 mm.

b) The average energy attributable to the fraction of the total radiation absorbed by 4 mm of lead seems to be 5 ÷ 10 MeV.

c) Approximately 10 times as many photons as electrons appear to be present in the ultra-soft radiation.

Observations by other authors may have a bearing on the existence of this ultra-soft component. The existence was demonstrated by Auger *et al.* (4) of small, local atmospheric showers which produced coincidences between unscreened counters all located within a radius of about 50 cm. Double coincidences between counters, assignable to a fairly soft radiation, were also found at a depth equivalent to 1,000 m of water by Barnòthy & Forrò (5,6), and later at depths equivalent to 600 and 540 m of water by Miesowicz, Jurkiewicz, & Massalski (7). The first two authors used a telescope of counters in coincidence and found an excess of double coincidences over triple coincidences in the extreme counters; they attributed this excess to a feebly ionizing radiation, perhaps a secondary radiation of μ mesons. MIESOWICZ, JURKIEWICZ, & MASSALSKI (7) partly confirm the excess of double coincidences observed by BARNÒTHY & FORRÒ (5, 6); they show that these excess coincidences are due to gamma rays with a lead absorption coefficient of about 1.4 cm^{-1} and suggest, though without offering further proof, that the gamma rays are derived from local radioactivity and are of energy of the order of 1 MeV.

As a contribution to the study of this almost unexplored field, the present authors decided to investigate the spectral composition of the very low energy gamma rays occurring in cosmic radiation. Use was made for this purpose of a single-channel scintillation spectrometer with a single sodium iodide crystal, whose assembly and calibration tests have been described in a previous paper (8). The crystal used in these measurements was a cylinder 5 cm high and 4.5 cm in diameter, and was screened with 0.7 mm of aluminium and a thin diffusing layer of MgO. A smaller crystal, 1.27 cm in height and of diameter also 1.27 cm, was used for the preliminary measurements only.

There are several remarkable advantages in this method, which has not been in use for very long: viz., a very high efficiency (practically unity with a crystal of the dimensions of the one used up to about 0.5 MeV, and never falling below 1/2), and a linear relation between the energy left by the gamma ray in the crystal and the amplitude of the resulting signal. The poor resolving power and the difficulty of deducing the spectrum of the incident gamma rays from the spectrum of potential powers are sometimes serious inconveniences; nevertheless, much more extensive data can be extracted, as will be seen, on the ultra-soft component of cosmic radiation by the use of this spectrometer than are obtainable from the GEIGER counters usually adopted.

The measurements which follow were carried out (together with many others which will be described elsewhere) during the period Jan. - July 1954.

2. *Orientation measurements.*

A series of preliminary measurements was first carried out in the laboratory under cover evaluated at about 100 g cm^{-2}. A rather smaller crystal was used (height = diameter = 1.27 cm) than that afterwards used in the final measurements. These measurements immediately showed a high concentration of pulses in the lower part of the spectrum (between about 50 and 200 keV) with a well-marked maximum at about 90 keV (fig. 1).

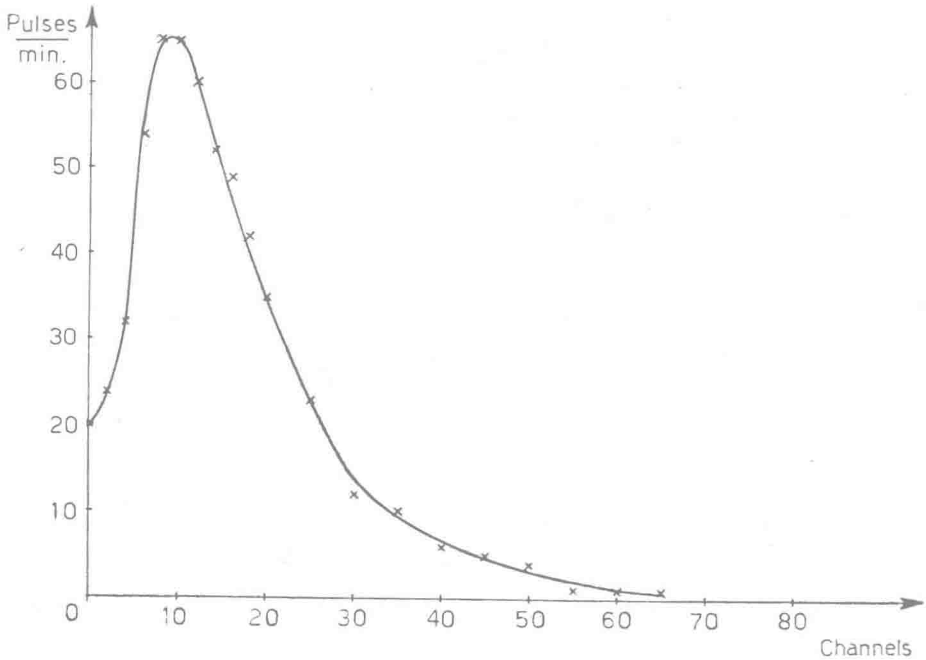

Fig. 1. — Spectrum of cosmic ray secondaries under 100 g cm^{-2}.

Such a result being quite unexpected on the basis of the work of BERNARDINI & FERRETTI [2, 3], the following three possibilities had to be taken into account:

a) An instrumental effect.

b) An effect due to the radioactivity of the walls or of surrounding objects.

c) A genuine effect of the cosmic radiation.

The following tests were made to permit the exclusion of the first alternative.

To begin with, the spectrum of the background pulses of the photomultiplier was examined in the absence of the crystal. Table 1 shows the total number of pulses registered at various amplifications with and without the crystal.

TABLE 1.

	Amplification	*imp./min.*
With crystal	17.8 keV/channel	1.668±29
Without crystal	17.8 » »	0
» »	2.18 » »	6±1
» »	1.64 » »	43±3

Fig. 2 shows the spectral distribution of the background pulses of the photomultiplier at an amplification equal to 1.64 keV per channel.

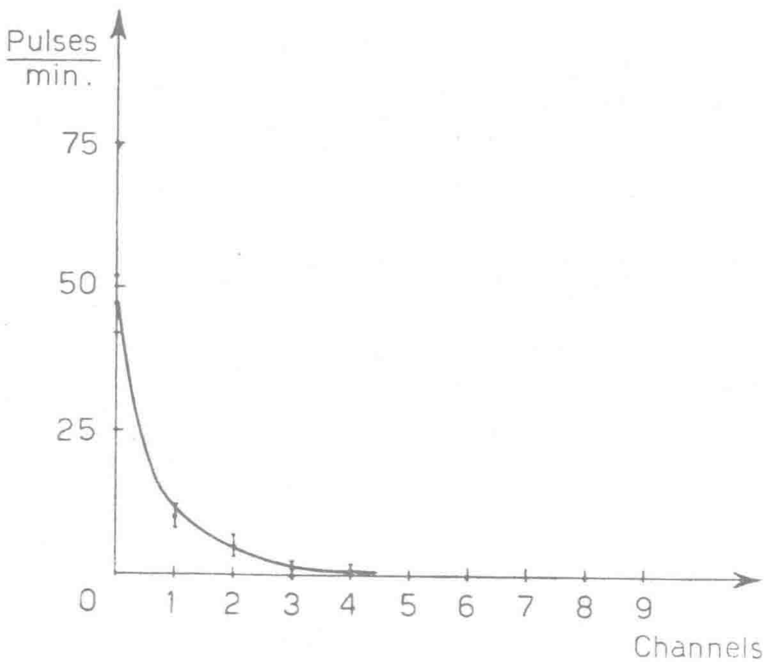

Fig. 2. — Background pulse spectrum of the photomultiplier.

The linearity of response of the apparatus was checked by the methods described in a previous paper already cited [8] with the crystal again in the spectrometer. A further check was made to verify that variations in amplification produced variations in the position and intensity of the maximum of the curve in fig. 1 in direct and inverse proportion respectively to the amplification.

Lastly, as a final confirmation of the non-instrumental character of the observed distribution, a pulse spectrum of the scintillation counter was made under the same conditions as those of fig. 1 but with the crystal screened on all sides by 2 cm of lead. Fig. 3 shows the spectrum obtained.

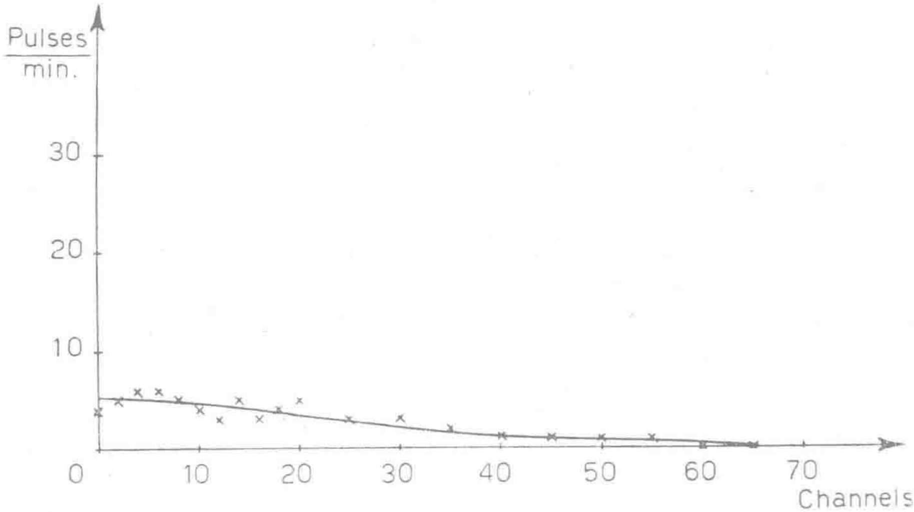

Fig. 3. — Spectrum with crystal shielded with 2 cm lead.

A rather more extensive investigation was called for in the case of the second of the alternatives listed above, i.e. that the effect observed is at least predominantly due to radioactivity of the walls or of surrounding objects. It may be remarked first of all that radiation of such low energy detected in the centre of a room in the laboratory, under cover of about 100 g cm^{-2}, is undoubtedly generated at least to a considerable extent in the walls and ceiling of the room. The problem was to determine whether this radiation consists of secondaries of radiation of external origin or is simply the result of radioactivity of the surrounding materials.

The first group of tests consisted essentially in changing the position of the crystal in the laboratory relative to the walls or ceiling, without changing the shielding, in order to observe possible variations of intensity or in the spectrum. No such variation could be observed (1) on varying the distance of the crystal from the walls from a maximum of 2.5 m to minimum of 2 cm; or (2) on removing the crystal to another room whose walls were covered with large cupboards of quite thick wood.

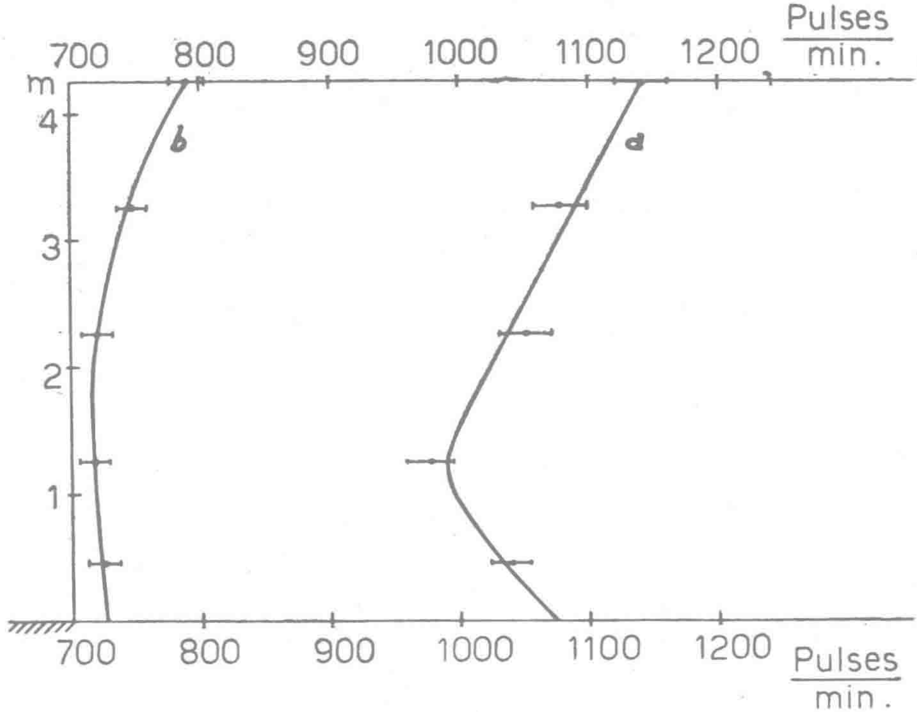

Fig. 4. — Total intensity in the laboratory, as a function of the distance from the ceiling.

Fig. 4 gives a series of results obtained by plotting measurements of the total intensity as a function of the distance of the crystal from the ceiling. Curve (*a*) was obtained with the crystal screened laterally with 5 mm of lead and curve (*b*) with the crystal screened above with 5 mm of lead as well. It may be seen that the intensity of the radiation derived from the upper hemispace remains constant within the errors; this indicates that the ceiling and the lateral walls of the room contribute more or less equally to this radiation.

The second group of tests was carried out to establish whether there is any preferred direction of incidence on the crystal for the radiation responsible for the observed pulses. A series of spectra were produced with partial lead screening of the crystal, and showed that the radiation is substantially isotropic on arrival. This fact is explicable in any case if the rays in question are gamma rays of very low energy.

In the third group of tests an attempt was made to establish whether the gamma rays derived from radioactive substances contained in the walls (i.e. essentially thorium, uranium, and potassium) could reach an

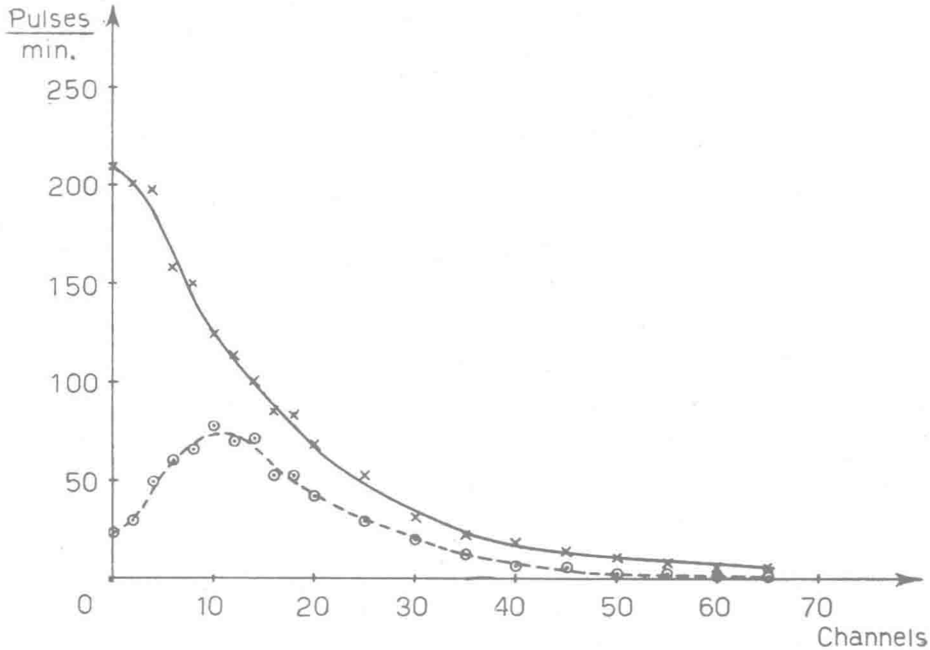

Fig. 5. — Spectrum with and without 400 mC radium source transmitted by the walls.

equilibrium spectrum in the walls themselves similar to that observed. To achieve this purpose a 400 mC radium source was placed in surroundings like those in which the spectrometer measurements were carried out and screened by several cm of lead in the direction of the crystal. Two thick structural walls of the building were interposed between the crystal and the source. In fig. 5 the two pulse spectra, measured in the presence and in the absence of the radium source, are compared. The difference between the two curves is plotted in fig. 6; this gives the pulse spectrum due to the presence of the source. It may be seen that the structure of this spectrum is quite different from the spectrum observed in the absence of the source: the maximum is displaced in the latter to a position below the threshold of the spectrometer. Assuming that the spectrum of fig. 1 is due to gamma rays from the walls, it seems a necessary conclusion that this spectrum has not reached its equilibrium configuration. This seems to be in agreement with the fact that the position of the maximum at about 90 keV closely coincides with the average position of the characteristc X-rays of the heavier elements of the thorium - uranium family. But the fact would still remain without explanation that this spectrum is clearly considerably richer in gamma rays of energy