Investigation of x-ray transition radiation in foamed plastic

A. I. Alikhanyan, É. S. Belyakov, M. P. Lorikyan, K. Zh. Makaryan, and K. K. Shikhlyarov

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Electron transition radiation in foamed-plastic targets of differing thickness and density is investigated. It is shown that the radiation intensity increases with growth of electron energy and also with growth of the plastic thickness and density, mainly at the expense of soft photons (5–25 keV).

The use of transition radiation in the x-ray region is now regarded as the most promising method in sight for identifying ultrahigh energy particles. Although this phenomenon was predicted theoretically back in 1959[1,2] and enjoyed a rapid early development[3-5], it has only recently achieved widespread recognition. This can apparently be attributed to the fact that the first experimental studies[6] indicated that the effect is weak. In an experiment on cosmic-ray muons with energies between 700 and 6000 GeV, a recording efficiency of the order of 10% was obtained. Moreover, in an experimental study of the transition radiation in periodic media[7], the same group of investigators obtained results that exceeded the theoretical values by an order of magnitude. These studies are examined in detail in[8]; here we merely note that these results are not entirely reliable and that the discrepancies that arose naturally did not favor the rapid development of this method.

General interest in transition radiation arose in recent years after the experiments reported in[9,10] had shed some light on the problem of reconciling the theoretical and experimental results. It turned out that the experimental results do not exceed the theoretical expectations after all. Moreover, it was found that the effect is not so weak as had been thought and that it can actually be used to detect particles. Further, it was found, and has been repeatedly confirmed[11-17], that one can set up a differential counting system based on transition radiation that is capable of distinguishing between π mesons, K mesons, and protons in single-pulse beams.

Another interesting result is the discovery of transition radiation in porous media[9]. First, this effect was unexpected from the point of view of resonance radiation and so was of definite theoretical interest; second, this discovery immediately simplified the problem of producing radiators of considerable area with a large number of transitions. The results of these studies were confirmed in [14-16,18], but no detailed study of transition radiation in porous media has yet been made.

Here we present detailed results of a study of the transition radiation in the 5–125 keV photon energy region produced by 1.0–3.75 GeV electrons traversing a foamed-plastic target, using the electron beam from the Erevan accelarator.

The experimental setup is shown in Fig. 1. After passing through a hole in the anticoincidence counter $\bar{S}_1$ and traversing the plastic foam target T, the electron beam (momentum spread $\Delta p/p \approx 1\%$) was bent in a magnetic field and recorded by two scintillation counters S_2 and S_3. The transition radiation photons were recorded with a detector consisting either of a multisection proportional counter (for 5–25 keV photons) or of a total absorption NaI(Tl) crystal scintillator (for higher energy photons).

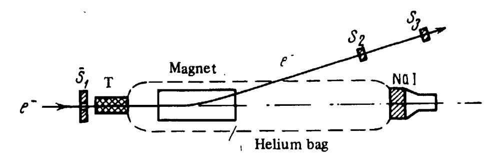

FIG. 1. Experimental setup.

The proportional counter consisted of twelve individual counters mounted in the same housing and isolated from one another by partitions consisting of 100 μm diameter steel wires stretched parallel at 10 mm intervals. The counters, each measuring $5 \times 5 \times 30$ cm, were mounted in six rows of two counters each so that there were 30 cm of gas in the path of the photons. The signal from each pair of counters was amplified and brought through a linear adder to a pulse-height analyzer. A resolution of 16% at the 13.8 keV line was obtained with a working mixture of 90% A + 10% CH_4 at atmospheric pressure. The amplitude characteristic was linear within 2% over the 5–30 keV interval.

It must be pointed out that the measurements of transition radiation spectra made up to now involve a serious error. When comparing the experimental results with theory one must make sure that the instruments have recorded only single photons, and not groups of them, since the pulses from a group of soft photons may pile up to simulate a smaller number of hard photons, thus leading to a systematic error in the measured spectrum. However, as far as we are aware, the number of photons was not monitored in any of the published studies, and a theoretical correction for this effect is not always reliable.

In the present work we took two signals from each pair of counters: the main pulse, and a second pulse, which was shaped in both length and height. The total height of the shaped pulses from all the counters was thus proportional to the number of photons recorded simultaneously throughout the entire detector. This technique made it possible simultaneously to investigate both the energy spectra of the radiation and the photon production multiplicity.

Figure 2 shows the differential spectra of the transition radiation produced in a plastic foam target 2 cm long having a density 0.04 g/cm^3 by electrons of several different energies (N_γ is the number of photons). The figure shows that the spectrum becomes harder with increasing electron energy, the dependence on the electron energy being stronger in the hard part of the spectrum than in the soft part.

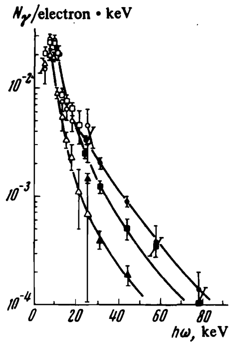

FIG. 2

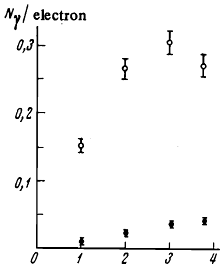

FIG. 3

FIG. 2. Differential spectra of transition radiation produced in a plastic foam target (thickness, 2 cm; density, 0.04 g/cm³) by electrons of the following energies (GeV): 1.0 (triangles), 2.0 (squares), 3.75 (circles). The points in the soft (5-25 keV) and hard (25-125 keV) regions of the spectra are represented by open symbols and black symbols, respectively.

FIG. 3. Total numbers of photons in the energy regions 5-25 keV (open circles) and 25-125 keV (black circles) versus the incident electron energy.

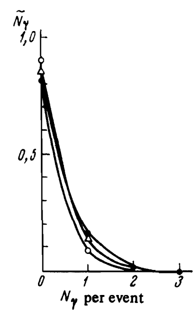

FIG. 4

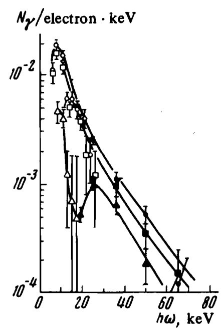

FIG. 5

FIG. 4. Photon multiplicity recorded with the proportional counter for the following electron energies (GeV): 1.0 (open circles), 2.0 (triangles), 3.75 (black circles). $\tilde{N}$ is the relative number of events with the given N_γ.

FIG. 5. Differential spectra of transition radiation produced by 3.0 GeV electrons in 1 cm thick foamed plastic targets having the following densities (g/cm³): 0.025 (triangles), 0.044 (squares), 0.090 (circles). The points in the soft (5-25 keV) and hard (25-125 keV) regions of the spectra are represented by open symbols and black symbols, respectively.

To illustrate this, we show in Fig. 3 the total numbers of photons in the soft region (5–25 keV) and the hard region (> 25 keV) as functions of the electron energy E_e. The curve for the soft region reaches a plateau at $E_e \approx 3$ GeV, while the curve for the hard region continues to rise. Figure 4 shows the photon multiplicity as recorded under these conditions with the proportional counter. We see that the photon multiplicity increases with increasing electron energy, and the number of events with two or more photons reaches 15% as compared with the single events at E_e = 3.75 GeV.

Figure 5 shows the effect of the density of the foamed-plastic target (target thickness, 1 cm) on the number of photons produced by 3.0 GeV electrons. A tendency toward saturation with increasing target density can be seen in the soft region of the spectrum, while the intensity in the hard region rises approximately linearly. This is clearly shown in Fig. 6, where we have separately plotted the total numbers of soft (5–25 keV) and hard (> 25 keV) photons against the target density. Figure 7 gives the photon multiplicities for the same target densities. The irregularity seen in the spectrum from the 0.025 g/cm³ target is apparently due to poor statistics.

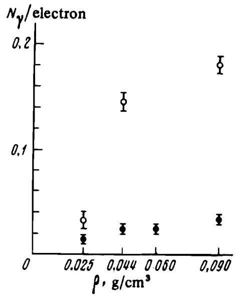

FIG. 6

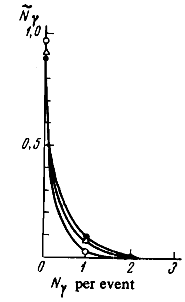

FIG. 7

FIG. 6. Total numbers of photons in the energy ranges 5-25 keV (open circles) and 25-125 keV (black circles) versus the density the foamed-plastic target. Correction: The ordinate of the leftmost open circle should be 0.09.

FIG. 7. Photon multiplicity for 3.0 GeV electrons on 1-cm thick foamed plastic targets of the following densities (g/cm³): 0.025 (open circles), 0.044 (triangles), 0.090 (black circles). $\tilde{N}$ is the relative number of events with the given N_γ.

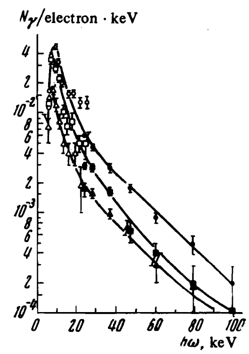

FIG. 8

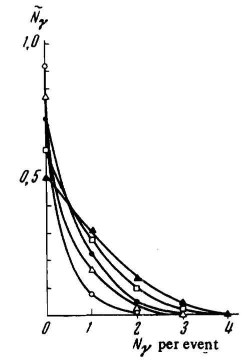

FIG. 9

FIG. 8. Differential spectra of transition radiation produced by 3.0 GeV electrons in three foamed plastic targets having the same density (0.04 g/cm³) and the following thicknesses: 1 cm (triangles), 2 cm (squares), 5 cm (circles). The points in the soft (5-25 keV) and hard (25-125 keV) regions of the spectra are represented by open symbols and black symbols, respectively.

FIG. 9. Photon multiplicity for 3.0 GeV electrons on fóur foamed plastic targets having the same density (0.04 g/cm³) and the following thicknesses: 1 cm (open circles), 2 cm (open triangles) 5 cm (black circles), 10 cm (squares), 25 cm (black triangles). $\tilde{N}$ is the relative number of events with the given N_γ.

All these observed saturation effects can be easily explained in terms of the zone in which the radiation is produced. The zone in which radiation is produced in vacuo increases with increasing electron energy, and is greater the lower the photon energy. For a given target, therefore, saturation sets earlier in the soft photon region. One can also explain the effects associated with the target density in this way.

Figure 8 shows the results of measurements of the transition radiation produced by 3.0-GeV electrons in three targets of the same density (0.04 g/cm³) but of different thicknesses (1, 2, and 5 cm). It will be seen that the proportional counter indicates about twice as many photons with energies near 25 keV from the thick (5 cm) target than does the scintillation spectrometer, although the data recorded with the two instruments for the thinner (1 and 2 cm) targets fit nicely. This difference can be explained as follows.

Figure 9 shows photon production multiplicity curves

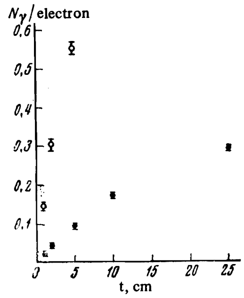

FIG. 10. Total numbers of photons in the energy regions 5-25 keV (open circles) and 25-125 keV (black circles) versus the thickness t of the foamed-plastic target.

for various target thicknesses. We see that for the 5 cm thick target, the number of events in which two or more photons were recorded reaches 25%, i.e., under these conditions our apparatus records multiple photons as single photons having the total energy. This obviously leads to an artificial hardening of the spectrum, as discussed above.

However, there is still another reason why the experimental spectrum derived from the proportional counter data is artificially high in the hard photon region. Suppose, for example, that we record two 10-keV photons as one 20-keV photon. Then when we correct the raw data for counting efficiency, the resulting intensity in the vicinity of 20 keV will naturally be too high by a factor equal to the ratio of the recording efficiency for 10-keV photons to that for 20-keV ones. In our case this factor exceeds two. Thus, there is an appreciable systematic increase in the apparent spectrum intensity in the region in which the recording efficiency is significantly lower than unity. The summation effect also affects the measurements made with the NaI crystal, but this additional increase in the hard part of the spectrum does not occur, since the recording efficiency is unity throughout the entire investigated photon energy range.

It should now be clear how important it is to monitor the photon multiplicity when measuring the spectra, especially when the radiator contains many (~ 1000) transitions. In view of what has been said, we may regard the agreement between the scintillation-spectrometer and proportional-counter data as satisfactory.

Figure 8 also shows that increasing the thickness of the foamed-plastic target has little effect on the soft region of the spectrum. This is better seen in Fig. 10, where we have separately plotted the total numbers of soft (5–25 keV) and hard (> 25 keV) photons versus the target thickness. The numbers of soft photons were measured only for targets up to 5 cm thick since the effect described above greatly distorts the spectra from thicker targets.

Thus, foamed-plastic is a good generator of transition radiation, and the energy spectrum of the photons lies in the same region as for layered targets; this means that plastic foam can be successfully used in transition-radiation particle detectors.

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