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Observation of the gradual increases and bursts of energetic radiation in association with winter thunderstorm activity

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Abstract: The dose rate of the gamma-rays increases in association with the activities of the thunderstorm. They were observed on the ground in the winter season of Japan. To investigate the time profile of the radiations during the winter thunderstorms, four sets of the radiation detectors were prepared which consist of the long proportional counters. These detectors have different characteristics of the response for the energy of the incident particles by mounting different thick shielding covers. Those results were compared with the results measured at the same time by the environmental radiation monitors set up around a nuclear power facility. Electric field was also measured by using a field mill. As a result, the following two types of the radiation enhancements have been found during the winter thunderstorm activities; the gradual variation of photon intensity with energy of a few MeV, and the burst type of the radiation that is attributed to the injection of high energy photons with the energy over 10 MeV.

Introduction

Variations of the intensity of the radiations within or above thunderclouds have occasionally been observed by the aircraft, the balloons and the artificial satellites equipped with radiation detectors [1], [2]. Fluctuations in the cosmic-ray intensity due to the thunderstorm have also been detected in mountainous areas [3], [4]. Furthermore, X-ray bursts originating from the lightning activities have recently been observed in the experiments on the rocket-triggered lightning and the natural lightning [5], [6]. These observed results may be distinguished by the radiation behaviors into two types: the gradual increases of the counting rate and rapid fluctuation of them. It is seemed that the former type of the fluctuation depends on the emission from the electric field of the thundercloud [7], and the latter type originates from the discharge process of the lightning [8].

In the coastal area facing the Sea of Japan, thunderstorms occur frequently during the winter season. There are several nuclear power plants in this area, including the reactor "Monju", which possess environmental radiation measuring instruments in order to monitor the gamma-ray dose by the plant operation. The increases of the gamma-ray dose-rate associated with winter thunderstorm activities have been observed around the nuclear facility by these instruments [9]. The observed dose-rate enhancements had the following features: (1) The durations of such enhancements were up to about one minute; (2) The affected areas seemed to be quite local, because in most cases, only one or two of environmental radiation monitors (ERMs) situated several hundred meters away from each other showed the increase of the dose-rate during the time of the activities of the thunderstorm; (3) The energy of the photons coming from the thunderstorm activities was up to several MeV. (4) The phenomena were observed only during the winter thunderstorms, and never observed in the summer thunderstorms.

In order to investigate the behavior of the energetic radiation detected by these ERMs, we conducted the observation using proportional counters (PRCs) in two winter seasons (2005 - 2006; 2006 - 2007), and detected seven significant fluctu-

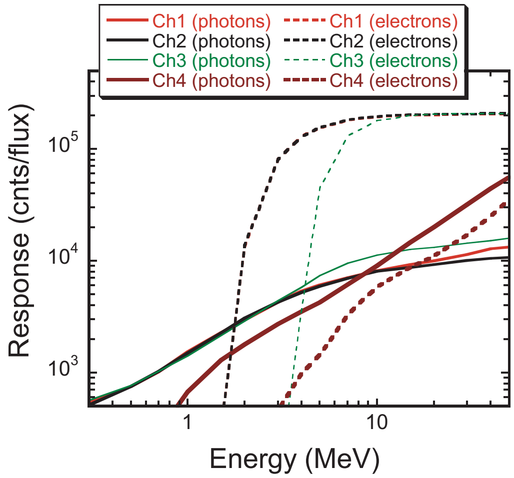

Figure 1: Energy response of each detector for electron and photon incidence.

ations of energetic radiation associated with thunderstorm activities. In particular, we measured them by the four sets of the detectors with different energy response characteristics by setting the different thick shields on them in the 2006 - 2007 winter seasons.

In this paper, we present the observed results obtained by using the PRCs, as well as the data by the ERMs and a field mill installed in the Monju site.

Experimental set-up

There are 16 PRCs in all, and each PRC consists of 2.5 m in length, 10 cm in diameter tubes, and the PR gas in the pressure of 0.9 kg/cm^2 is filled in the PRC. Since the detector is connected four PRCs in parallel, the radiation is measured by summing up the signal of these PRCs. Two detectors were not covered by the shield (Ch1, Ch2), and we covered two of the rest by the shield: one set of the detector covered by the acrylic board with 1 cm in thickness (Ch3), and the other with a lead plate of 1.5 cm in thickness (Ch4), respectively. The reason that we set up these shields is to understand the dominant particles and their energies generated in the thundercloud. Here, we calculated the energy response of each detector by the Monte Carlo calculation. The result is shown in Fig. 1. Since the sensitivity of the PRC is high for energetic electrons, the detector with the acrylic cover was set up to evaluate the energetic electron incidence. The detector with the lead cover is equipped to shield the low energy gamma-rays, as well as such electrons.

The counting rate of each detector was sampled every 0.1 seconds. Moreover, in order to investigate the lightning activities, the field mill was installed in a point about 50 m away from these detectors, and the fluctuation of the electric-field was measured every one second. The times of these data observed by the radiation detectors and the field mill have been synchronized by using the GPS system.

Experimental results

The significant fluctuation of the radiation was observed three times in the winter from Dec. 2006 to Feb. 2007. Twice the events both a radiation burst and a gradual fluctuation were observed, and only once the event with a burst was detected. As an example of the former event, Figs. 2 and 3 show the results of the fluctuations of the radiation and the electric field observed in Jan. 7, 2007.

A gradual increase of the fluctuation continued for about one minute, and a steep electric field fluctuation followed that showed the lightning discharge occurred when the counting rate of the radiation returned to a usual level. In addition, the radiation burst had been generated after the lightning discharge. The time of a rapid fluctuation of the electric field corresponded to the time that the lightning location detection system (LLS) of Japan Weather Association detected a cloud-to-ground lightning. Moreover, the time that the radiation burst detected by the PRCs was corresponding to the time that showed a steep rising of the dose-rate by the ERMs installed in the site. These ERMs were the system independent from the PRC system for the power supply unit and the measurement unit. As shown in Fig. 3, a noticeable time lag, about one second was observed in the time that the lightning discharge and the radiation burst was generated.

Since a multi-channel analyzer (MCA) is installed in the NaI detector system of each ERM, the pulse-height distribution was measured continu-

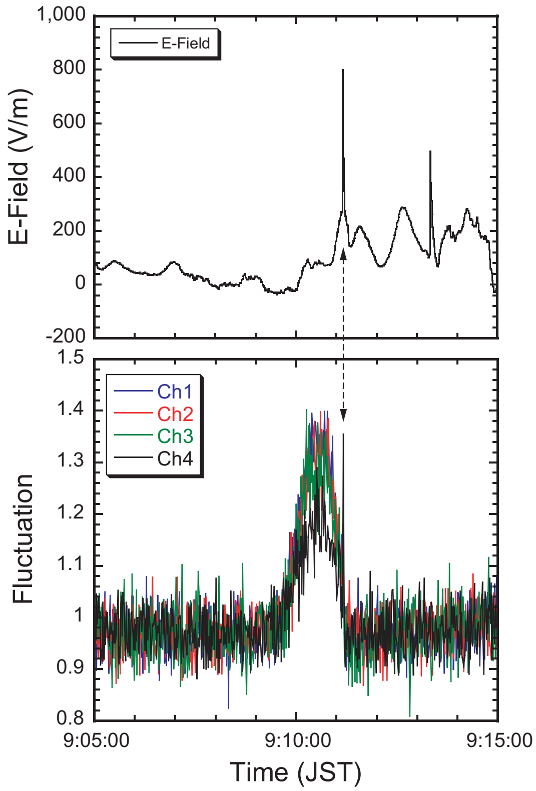

Figure 2: A fluctuation of the electric field and the radiation observed on Jan.7. The radiation level is normalized by one minute average of each detector.

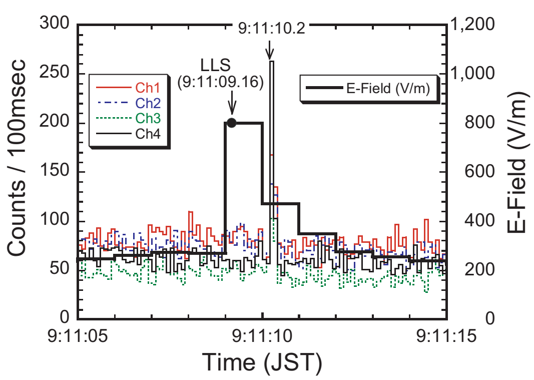

Figure 3: Fluctuation of electric field and the counting rate of the PRCs at around the time when the radiation burst was detected.

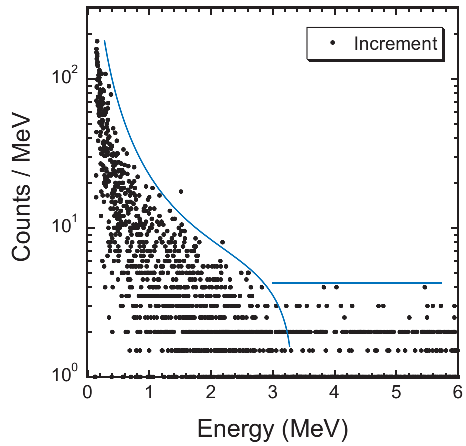

Figure 4: "Net" pulse height distribution of the NaI(Tl) detector of an ERM during dose-rate enhansement observed during the thunderstorm activity in Jan. 7, 2007.

ously, and stored them every 20 minute. Figure 4 shows the "net" pulse height distribution made by the lightning activity. That is a spectrum during a period of 20 minutes including the time of the dose-rate increase, subtracted from the average spectrum observed during the preceding and following 20 minutes. From this figure, two components seem to be included in the pulse-height distributions: the low energy component of about 3 MeV or less, and high energy component over 3 MeV.

Besides above an event, a similar event was seen in Feb. 1. However, the fluctuation were not larger than the event on Jan. 7. At this event, a lightning discharge occurred immediately after having returned to the former level as a gradual fluctuation continued for about one minute. In addition, a radiation burst had been produced one second after that lightning discharge. Furthermore, a radiation burst was occurred on Dec. 4, 2006. At that time, a gradual fluctuation was not detected, and the burst generated 0.9 second after a lightning discharge.

Discussion

Two types of variations of low energy cosmic ray intensities have been observed in association with

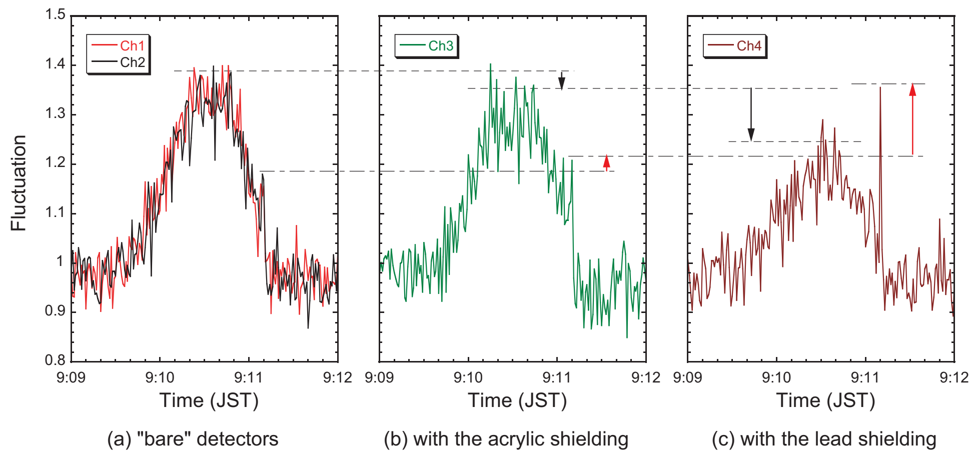

Figure 5: The time variation of the counting rate of the bare detector (a), the detector with the acrylic shielding (b), and that with the lead shielding (c).

the winter thunderstorm activities. As a result of the measurement by using the PRCs, different behavior of the fluctuation was seen to the different thickness of the shield during the thunderstorm activities. While the "bare" detectors have shown the highest ratio to the background value compared with that of other detectors at the gradual increase, an opposite tendency was seen at the burst (see Fig. 5). From these results, it is considered that photons with the energy of 1 – 3 MeV are dominantly produced at the gradual increase, while high-energy photons over 10 MeV are produced mainly at the time of the radiation burst. From the results by the ERMs, not only show the time variation similar to the results of the PRCs but also the pulse-height distribution of the MCA, as shown in Fig. 4. This suggests the above-mentioned result. However, the reason why the burst time and the time of lightning discharge have shifted for about one second has not yet been well understood at the present stage and it may be a future task of the study.

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