Proceedings of the Second International Workshop on EGS, 8.-12. August 2000, Tsukuba, Japan
KEK Proceedings 200-20, pp.324-329

Observation of Intense Radiation During Thunderstorm and Monte Carlo Simulation of Bremsstrahlung Generation

T. Torii[1], M. Takeishi[1], T. Hosono[1] and T. Sugita[2]

[1] *Tsuruga Head Office, Japan Nuclear Cycle Development Institute, Shiraki 2-1, Tsuruga, Fukui-ken 919-1279, Japan*
[2] *Science and System Lab. Inc., Sumiyoshi 1342-6, Tomobe, Ibaraki-ken 309-1716, Japan*

1 Introduction

Following Wilson's suggestion[1] of electron acceleration by the electric fields in thunderclouds, a number of experiments were attempted to investigate whether or not energetic electrons and bremsstrahlung X-rays were generated by thunderstorm electric fields or lightning discharge processes. In recent years, enhanced radiation at high altitude has been detected in experiments using scintillation detectors on a jet[2, 3] and an artificial satellite[4], demonstrating that radiation is indeed associated with lightning activities. However there are few experimental reports of detection near the ground since Whitmire's investigation[5] using thermoluminescent dosimeters (TLDs) in 1979.

In winter, many thunderstorms occur on the west coast of Japan, and it has been suggested that gamma-ray dose may increase occasionally during winter thunderstorms[6]. Recently, a gamma-ray dose enhancement which might be caused by the lightning activity was measured by TLDs and environmental radiation monitors around the site of the fast breeder reactor "Monju", a nuclear power plant facing the Japan Sea. (see Fig. 1)

2 Observation

On the night of Jan. 28, 1997, there was a thunderstorm lasting until dawn, during which there was much lightning activity in the area accompanied by snow. In particular, a large lightning flash occurred at 4:31 JST on Jan. 29. At that time, dose-rate of the environmental radiation monitors using an NaI(Tl) detector around the site increased transiently. Furthermore, radiation monitors installed on the most upper floor in the buildings were affected at that time. During that night, although 20 cloud-to-ground discharges were detected by the LLS (Lightning Location System) around Tsuruga Peninsula, a dose-rate increase of the NaI(Tl) detectors was recorded only once. Some radiation monitors installed in the buildings were rose count-rate at that time, and all of those were set on the most upper floor. Dose increases were also measured by TLDs exposed during the periods which included the day when the lightning occurred. Absorbed doses of the TLDs exceeded over 3σ of the mean values at almost all of the measuring points outside the buildings of Monju (see Fig. 2), and highest dose increase was recorded about 0.1 mGy at the north-east area of the site. Whereas doses in the buildings were within the normal range at all measuring points.

3 Energy Spectrum and Dose Estimation

The NaI(Tl) detector system of the environmental radiation monitor (MP-1) is connected to a multi-channel analyzer (MCA) with 2,048 channels in the energy range up to about 5 MeV, and the

MCA stores the pulse-height distribution at one hour intervals. Fig. 3 shows dose rate indicated by the monitor and the pulse-height distributions of the MCA around the time that the lightning occurred. From "net" pulse-height distribution, which is the pulse-height distribution subtracted from the background distribution, we calculated the photon energy spectrum by the unfolding method. Here, we used a versatile code SAND II for the spectrum unfolding, and EGS4/PRESTA code[7, 8] for the response calculation of the NaI(Tl) detector system. The unfolded energy spectrum is illustrated in Fig. 4(a). This indicates a continuous spectrum with energy up to several MeV, and dose increase is estimated about 36 nGy at that time. It is quite different from dose increase obtained by the TLD at the same point (TL-E1). It may be caused by dead time losses of the detector and the MCA system, and low and/or high energy component cut off by the MCA.

4 Discussion

As mentioned above on the measured result of TLDs and radiation monitors, it is seen that this dose enhancement is caused by external radiation. Also, from the unfolded spectrum, this phenomenon may be caused by bremsstrahlung X-rays from energetic electrons generated in the thunderstorm. Next, we calculated X-ray spectra on the ground generated from downward electrons emitted at 500 m and 1,000 m high, which is altitude of the base of thunderclouds. As shown the results in Figs. 4(a) and 4(b), the unfolded spectrum is consistent with the bremsstrahlung spectra.

4.1 Electron transport in electric fields

To verify the electron acceleration and the bremsstrahlung generation in thunderstorms, we have made macros to calculate electron behavior in air with external electric fields according as Bielajew's manner[9]. The macros

```
$SET-TUSTEP-EM-FIELD;,
$SET-USTEP-EM-FIELD;,
$SET-ANGLES-EM-FIELD;,
..............................,
```

have been located within `SUBROUTINE ELECTR`.

Here, we have put the following equations described electron transport in the macros.

- Transverse force on the electron due to external fields:

$$\begin{aligned} \vec{u}_f &= \vec{u}_0 + \Delta\vec{u}_{ms,ret} + \Delta u_{ex}, \\ \Delta\vec{u}_{em} &= \frac{es}{m_0\gamma(E_0)\ {v_0}^2}(\vec{D}_0 - \vec{u}_0(\vec{u}_0 \cdot \vec{D}_0)), \end{aligned}$$

where $\vec{u}_f$, $\vec{u}_0$ are final and original unit direction vector, respectively. $\Delta\vec{u}_{ms,ret}$ is the deflection due to multi scattering and inelastic collisions, and Δu_{ex} is that due to the external electric field.

- Final position and energy of electrons:

$$\begin{aligned} \vec{x}_f &= \vec{x}_0 + \vec{u}_0\ s + \frac{s}{2}(\Delta\vec{u}_{ms,ret} + \Delta\vec{u}_{ex}), \\ E_f &= E_0 - \Delta E_{ret} + e\vec{D}_0 \cdot (\vec{x}_f - \vec{x}_0) \end{aligned}$$

where ΔE_{ret} is the energy loss due to inelastic collisions.

4.2 Simulation in thunderstorm

After a test of electron transport in a vacuum to verify the behavior with the analytical solution, we modeled electric fields in thunderclouds and calculated the transport using the above code. As shown in Fig. 5, it is obtained that the avalanche of electrons caused by the acceleration and collisions occurred at a field strength of about 3 MV/m for electrons with energy up to 1 MeV as a original energy. Furthermore, it can be seen that bremsstrahlung X-rays generated at high altitude above the ground. Details are presented at the workshop.

References

[1] Wilson, C. T. R., *Proc. Cambridge Phil. Soc.*, **22**, 534 (1925)

[2] Parks, G. K. et al., *Geophys. Res. Lett.*, **8**, 1176 (1981)

[3] McCarthy, M. and Parks, G. K., *Geophys. Res. Lett.*, **12**, 393 (1985)

[4] Fishman, G. J. et al., *Science*, **264**, 1313 (1994)

[5] Whitmire, D. P., *Lett. al Nuovo Cimento*, **26**, 497 (1979)

[6] Yoshioka, M. et al., *Annual Rep. of Fukui Pref. ERMC*, **16**, p129 (1993) (in Japanese)

[7] Nelson, W. R., Hirayama, H., and Rogers, D. W. O., *SLAC-265*, (1985)

[8] Bielajew, A. F. and Rogers, D. W. O., *Nucl. Instr. Meth.*, **B18**, 165 (1987)

[9] Bielajew, A. F., in *Monte Carlo Transport of Electrons and Photons* (Jenkins, T. M., et al., eds), 421 (1988, Plenum Press, N.Y.)

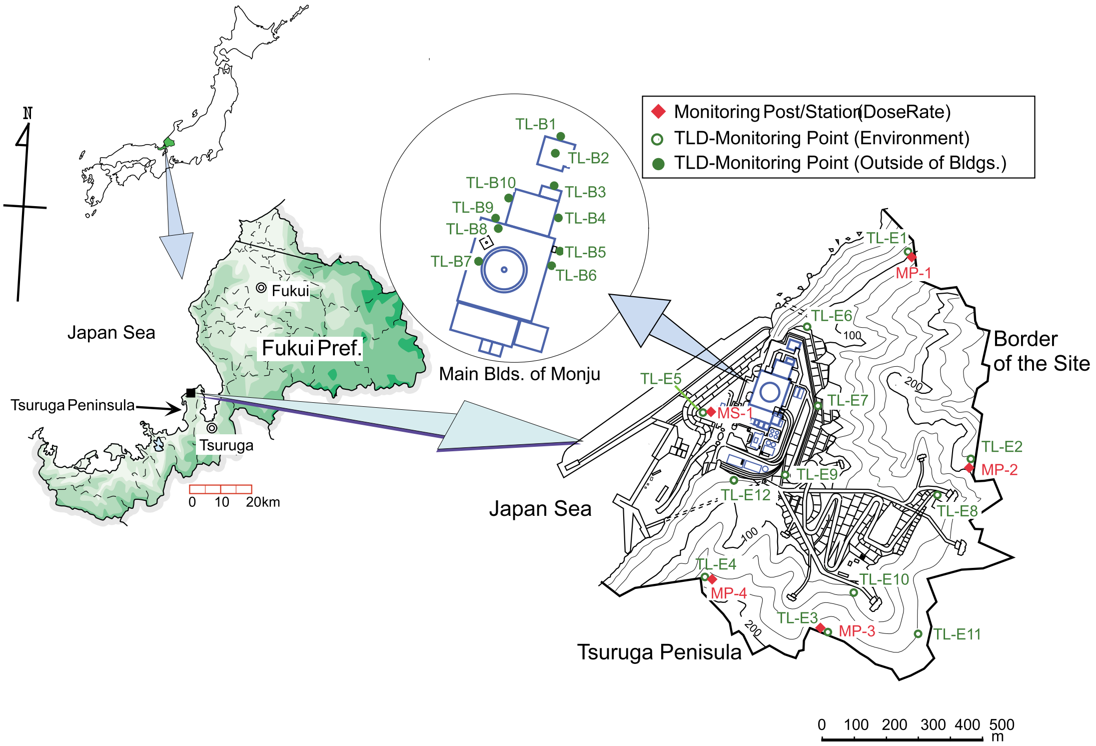

Figure 1 Radiation Monitoring Points in the Site of "Monju"

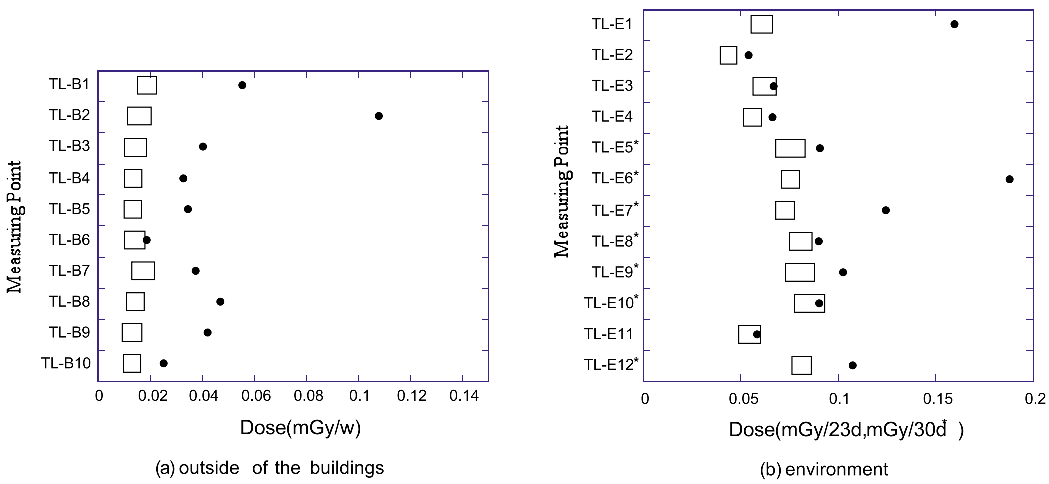

Figure 2 Dose Measured by TLDs During the Time the Lightning Occurred and Usual Range at Each Point

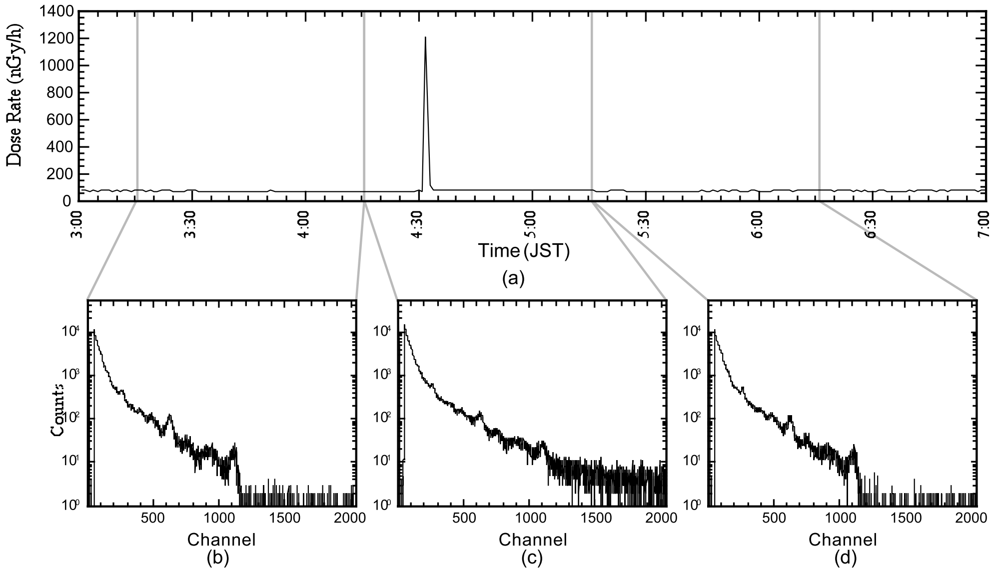

Figure 3 Dose rate and Pulse-Height Distributions of the NaI Detector

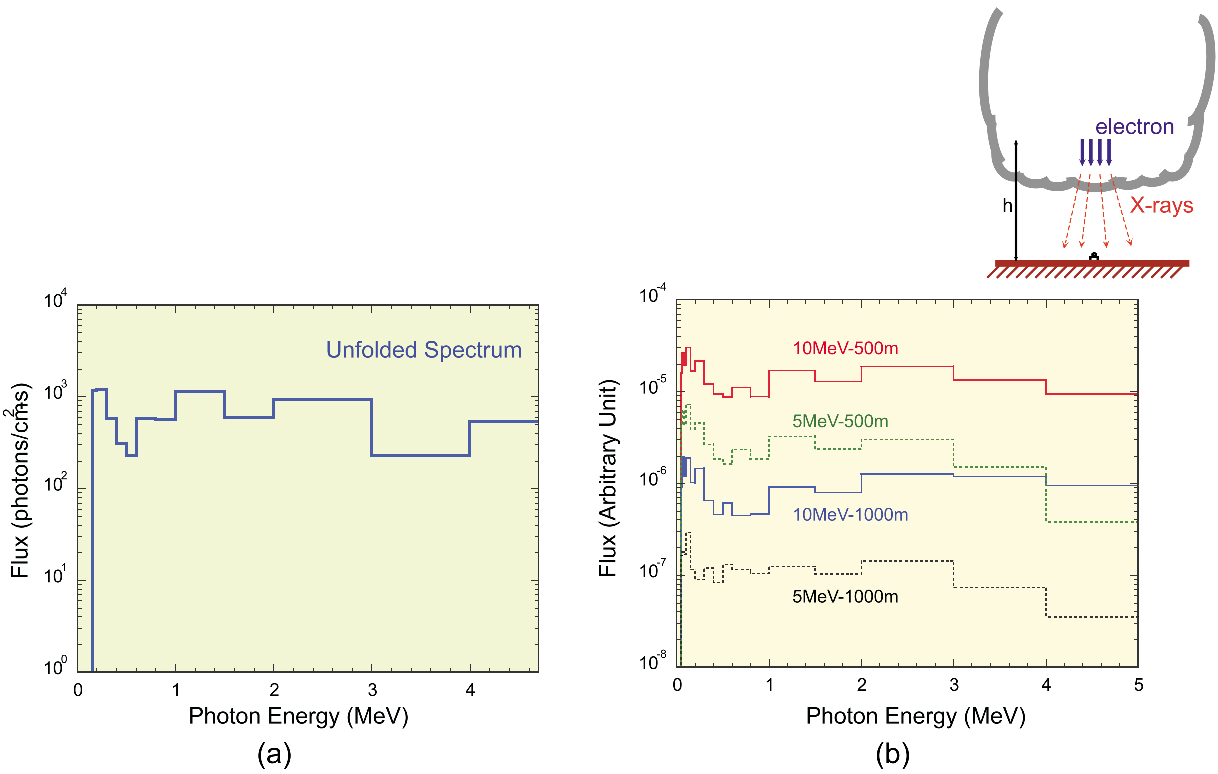

Figure 4 Unfolded Spectrum (a) and Calculated Bremsstrahlung X-Ray Spectra

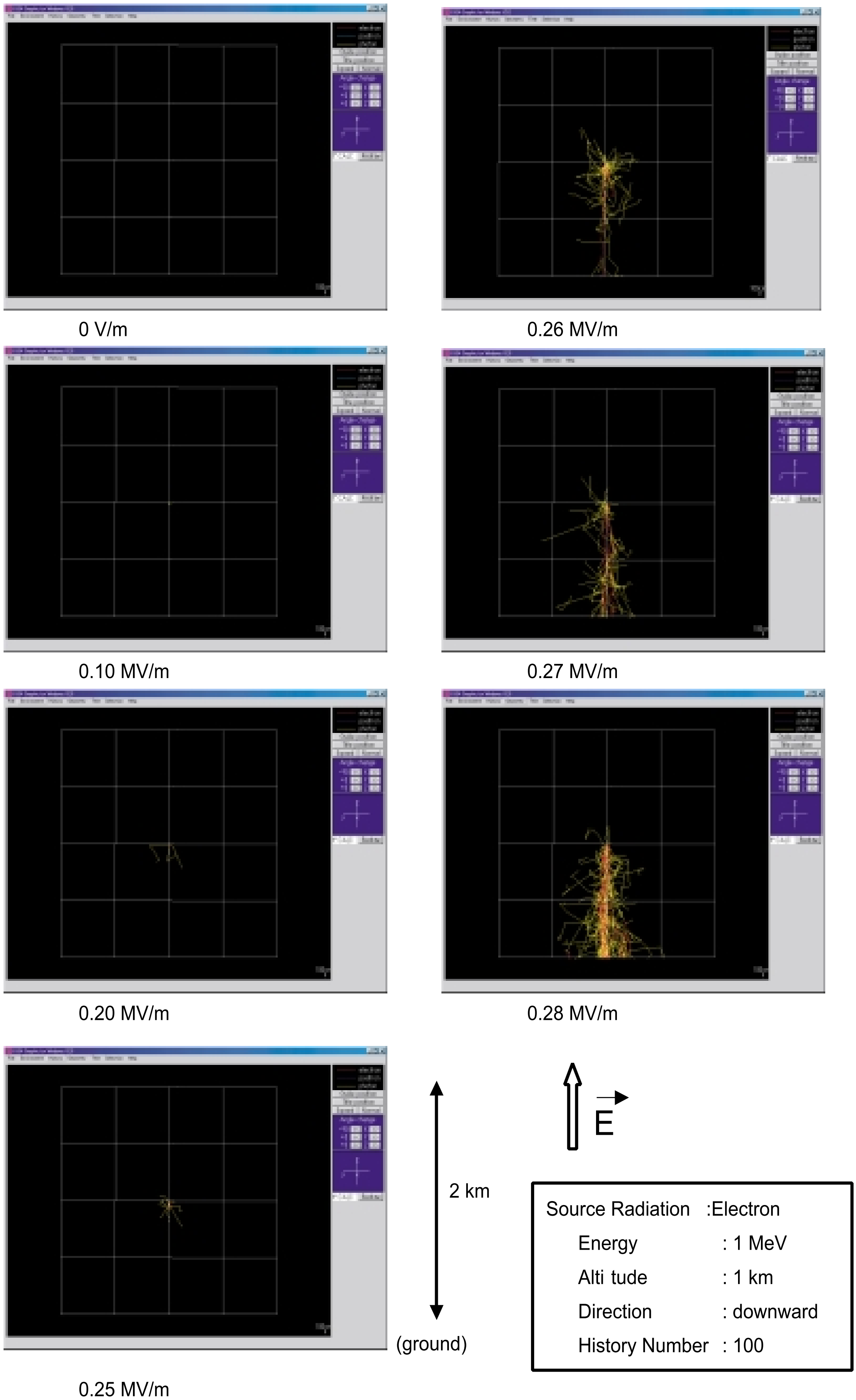

Figure 5 Electron and photon trajectories in electric fields simulated thundercloud