Burst profile of the lightning generated neutrons detected by Gulmarg Neutron Monitor

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Abstract: Lead-free Gulmarg Neutron Monitor operating at High Altitude Research Laboratory, Gulmarg has been used to detect neutrons following the initiation of a lightning discharge. Having given the first experimental evidence of neutron production in the lightning discharges, the system has been subsequently modified to record the time profiles of the neutron bursts produced following the initiation of lightning discharges. This has been achieved by implementing an ingenious hardware and software technique in the redesigned Atmospheric Lightning Detection System of Gulmarg Neutron Monitor. The system has successfully detected several major neutron burst events after the initiation of the lightning in the vicinity of the detector. The profiles of these neutron burst events have been monitored and are presented in this work. The study confirms production of neutrons in atmospheric lightning discharges and the observed time profiles could be important in determining possible mode of neutron production.

Introduction:

The experimental studies conducted on high voltage discharges of high power [10^{12} watt] and short duration [$5x10^{-8}$ sec] through thin deuterated polymer fibres have revealed production of 2.45 MeV neutrons [1]. The neutron production is attributed to deuteron-deuteron fusion reaction within the plasma of the discharge. Depending upon the concentration of deuterium present in these fibres, the yields in the range of 10^7 to 10^{10} neutrons per discharge were obtained in these experiments. In addition, in the experiments [2], a discharge of 12-kilo joule through a deuterated gas with a short circuit current of $1.91x10^6$ A is seen to generate a burst of 10^8 to 10^{10} neutrons. The production of such neutrons confirms the presence of nuclear reactions of energetic ions in such plasmas. Based on these investigations, it was postulated [3, 5] that neutrons might also be produced in natural lightning discharges due to the fusion of deuterium present in the atmospheric water vapour. Comparing the parameters involved in a natural lightning discharge channel and exploding wire experiments, It was suggested [3, 4, 5] that ~10^{15} neutrons can be produced by a natural lightning discharge. But in the experiments [4] in which fission track detectors were placed near lightning arrestors failed to ascertain significant neutron production in lightning discharges and estimated an upper limit of $2.5x10^{10}$ neutrons per lightning stroke. However, the first experimental evidence of detecting lightning generated neutrons [6] on event-to-event basis was given by using lead-free Gulmarg Neutron Monitor at HARL, Gulmarg as the detector.
With 3% efficiency for 2.5 MeV neutrons and a large detector area, the lead-free Gulmarg Neutron Monitor (GNM) detects neutrons following the initiation of a lightning discharge [6]. An antenna placed near the neutron detector of GNM senses an electrostatic field change associated with the lightning discharges. Earlier, the neutron counting was done in a predetermined time interval of 320 microseconds, large compared to the duration of a lightning stroke. However, the system was not in a position to record the profile of the neutron bursts and was accordingly redesigned in a major way to record burst profile of lightning generated neutrons. Besides, an ingenious hardware and software technique is imple-

mented in the electronics system to extract the exact information regarding the detection of the first neutron and the number of lightning strokes before and after its detection. The modified electronic system has a recording time resolution of one microsecond. The system is capable of recording fourteen differential time-delays due to the successive field changes in the vicinity of the detection system. Arrival time profile and the intensity of the detected neutrons are recorded in sixty-three neutron-counting gates of twenty microseconds each.

The Monitor besides being used as atmospheric lightning neutron detection system is also used in studying the continuous background cosmic ray spectrum and the solar modulation of cosmic rays. Several major lightning events have been recorded in the recent past since the integration of redesigned electronics into GNM.

Experimental setup

The lead-free neutron detection system at Gulmarg is a modified version of the original IGY type cosmic-ray neutron monitor. The producer lead is removed completely and 28 BF3 counters, each 90 cms long and 3.8 cms in diameter are spread in the form of a pile of surface area of $3x10^4$ cm^2. The counters are laid on 28 cm thick paraffin and are covered on top by 8 cm of paraffin sufficient to thermalize 2.45 MeV neutrons. This monitor has a count rate of about 36000 per hour and monitors, round the clock, low energy neutrons produced due to the interaction of cosmic rays with atmosphere.

GNM is integrated with the redesigned electronic system for recording neutrons for a time interval of several hundred microseconds following the sensing of a lightning discharge. Moreover, a multi-stroke lightning circuit is used for recording differential times between successive strokes of a multi-stroke lightning flash. The system is activated when an antenna placed near the neutron detector senses the electrostatic field change associated with the lightning discharge. The detector senses this electrostatic field change almost instantaneously compared to the time taken by a 2.45 MeV lightning generated neutron that escapes the scattering of constituent nuclei of the atmosphere and reaches to the detector. The time-delay between the sensing of the electrostatic pulse and the detection of the first neutron by the detector gives a measure of the distance from the detector to the lightning channel. This neutron time-delay, with a one-microsecond time resolution, is recorded electronically in six hex counters [74LS393] organized as six-digit hex-cache. Thereafter the detected neutron pulses are counted in sixty-three neutron-counting gates by two hex counters [74LS393] organized as two-digit hex-cache coupled with an octal latch [74LS374] at output. Monostable multivibrator [74LS123] is utilized to generate these gates consecutively in re-triggering mode. The gate-width is continuously adjustable from 5 to 75 μsecs. However, presently the gate-width is pre-fixed at 20 μsec enabling the system to have a total neutron recording time of 1260 μsec. At the end of the completion of each neutron gate, the count from the latch is transferred to sixty three successive addresses of two parallel columns of the 64-bit RAM [74LS189] organized as 16x4 word each for storage. Similarly, time-delay between successive strokes of multi-stroke lightning event is counted simultaneously and separately by six hex counters [74LS393], organized as six-digit hex-cache coupled with three octal latches [74LS374] at output. At the sensing of next electrostatic field variation, the differential time-delay is transferred to the same RAM that is used to store time- delay information of the first detected neutron. This time delay information is transferred to the RAM at the instant when the first neutron after the sensing of the lightning flash is detected. This technique allows us to extract information about the number of strokes before and after the first detected neutron. When all the sixty-three neutron-counting gates are over, the whole system closes. Subsequently, the data from the RAM is transferred to the PC through RS232 serial interface and the RAM is re-written with zeros. The system now remains ready for the next event.

Results and Discussion

During May and June 2006, major thunderstorm activity occurred in the vicinity of GNM. The Lightning Neutron Detector System triggered sixty times by natural lightning discharges during this period. In each event, time-delay between the sensing of the lightning discharge and the detection of the first neutron as well as the number of

ICRC 2007 Proceedings - Pre-Conference Edition

neutrons detected within a total time interval of 1260 μsec was recorded. The number of strokes and differential delay between the strokes in each lightning event was also recorded. Out of these 60 triggering 50 events recorded $\geq$ 3 neutrons per event in 1260 μsec. We show here the plots (Fig. 1) for four major lightning events. Each point on the graph depicts the number of detected neutrons grouped into consecutive time intervals of 80 μsecs for the total neutron recording time interval of 1260 μsec. Seen from top of the illustrated figure, the first plot shows a single-stroke event and has recorded 63 neutrons with a time delay of 14791 μsec. The second plot shows a two-stroke event and has recorded 24 neutrons with a time delay of 18 μsec. The third plot shows a two-stroke event and has recorded 50 neutrons with a time delay of 14770 μsec. The fourth plot shows a three-stroke event. Three of the plots show well-defined rise and fall in detected neutron intensity. In all the three cases, the integral time-delay (The sum of the neutron time-delay and the neutron recording time-interval of 1260 μsec) is greater than 14000 μsec. In addition, the peak intensity of neutrons is recorded approximately in between 500 to 1100 μsec of the recording interval. In one of the major events on 01/05/06 at 18:01:39 hrs IST, 63 neutrons were recorded with a time-delay of 15095 μsecs. The event is of multi-stroke type and generated two strokes with a differential time-delay of 1 and 8 μsec respectively from sensing the occurrence of the first discharge. All these strokes occurred before the detection of the first neutron by the system. Another event recorded on 01/05/06 at 20:12:46 (IST) is interesting as it was recorded at the time of a lightning strike to a tree located at ~ 300 m away from the detector. Twenty-four neutrons were detected in the total recording time interval of 1260 μsec in this 2-stroke event. The second field change was recorded at 807 μsec after sensing of the first lightning discharge. The detection of the first neutron, which occurred after a time-delay of 18 μsec, places its source at a distance of 296 m (almost equal to the actual measured distance of 300m) away from the detector on the basis of the distance calculation formula 'd ' given by :

$$d = 13.5 \times 10^6 \times \Delta t \times E^{1/2}$$

Where 'E', equivalent to 2.45 MeV, is the energy of the neutron and 'Δt' is the observed time-delay of the first detected neutron. Thus, it seems that the 2.45 MeV neutrons recorded by our system were produced in this lightning discharge.

However, a discrepancy exists at present as to the mode of production of these neutrons in the lightning bolts. The reported temperatures associated with the plasma in the discharge column of a lightning bolt approaches to 3×10^4 K which is several orders of magnitude lesser than that needed for occurrence of thermonuclear fusion process. Nevertheless, there are some hot spots in the lightning channel where pinch effect could create plasma configurations in which ions may have competing peak energies to induce fusion reactions. Evidence has been gathered regarding emission of high energy gamma ray from lightning discharge channels [7]. Recently, it has been suggested [8, 9, 10, and 11] that these high energy gamma rays originate from a Runaway Breakdown (RB) process in the thunder cloud during lightning discharge. The Runaway Breakdown and subsequent lightning discharge process could be initiated by a high energy "seed" electron produced during a cosmic ray shower. For Runaway Breakdown process to take place the electrical fields existing at the time of thunder storm in the atmosphere could be allowed to be an order of magnitude lower than the known conventional break down field. In RB process, an avalanche of electrons produced and accelerated to relativistic energies could interact in the vicinity of the nuclei to produce bremsstrahlung radiation and conceivably, such a radiation could interact with other nuclei through photoneutron nuclear reactions to release neutrons.

Conclusion

We confirm the production of neutrons in atmospheric lightning discharges. The data obtained from the redesigned Atmospheric Lightning Detection System integrated with GNM has revealed a pattern in the emission profile of neutrons produced in lightning discharges.

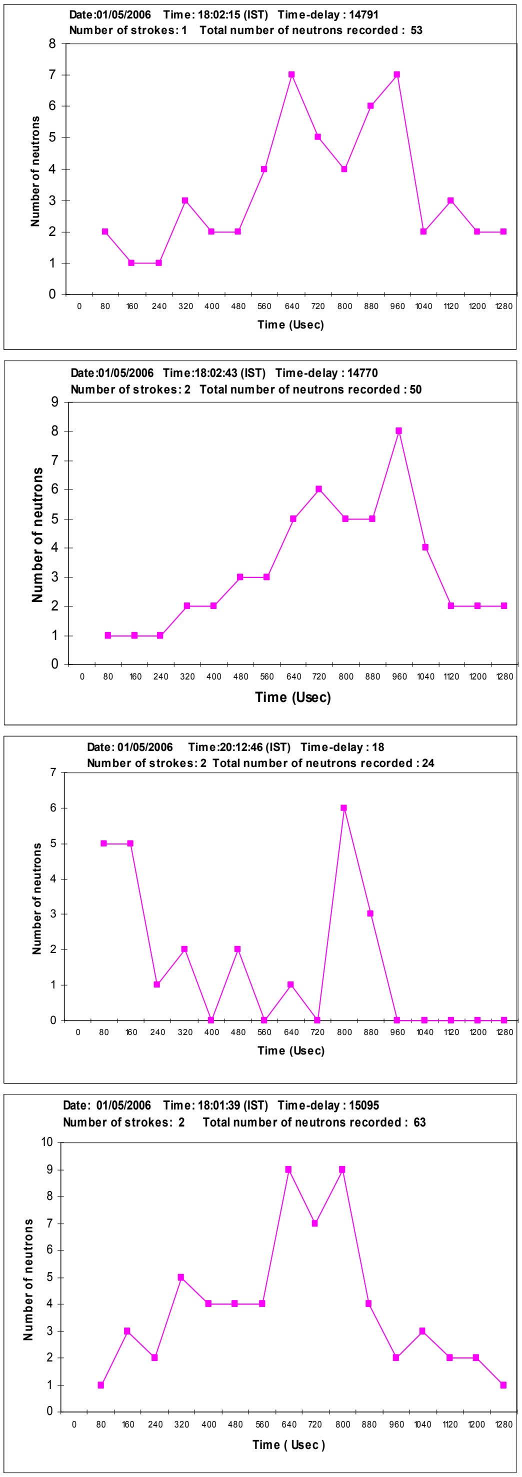

Fig: 1

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