Lead-Free Gulmarg Neutron Monitor observes 2.45 MeV neutrons co-related with natural atmospheric lightning discharges

P. M. Ishtiaq, S. Mufti, M. A. Darzi, T. A. Mir, G. N. Shah*

Nuclear Research Laboratory, Astrophysical Sciences Division, Bhabha Atomic Research Centre
Srinagar - 190006, Kashmir, India

**52-Hamzah Colony Bemina, Srinagar - 190012, Kashmir, India*

Abstract

The first experimental evidence of detecting the neutrons co-related with the natural atmospheric lightning discharges (NALD) was obtained with Lead-Free Gulmarg Neutron Monitor (LFGNM) operating at High Altitude Research Laboratory(HARL), Gulmarg, Kashmir, India and was reported in the year 1985 [1]. The neutron observations still continue with LFGNM. However, the current configuration of LFGNM is the upgraded version of the system used earlier to record neutron bursts (in the recording period of 320 μs in four electronic gates of 80 μs each) supposedly originating from an NALD. In the current system the neutron recording time period/interval has been extended to 1260 μs with 63 gates of 20 μs each. The system also simultaneously records the differential times- maximum upto fourteen- between the consecutive strokes of a multi-stroke lightning flash. The distance between an NALD channel and LFGNM setup is empirically determined by making use of the time delay (t_d)/time of flight (TOF) measurement of the first detected neutron subsequent to the sensing of the electrostatic field variation

Email address: pishtiaq@gmail.com (P. M. Ishtiaq)

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caused due to the initiation of an NALD in the ambient atmosphere of the LFGNM setup. Assuming *a priori* incident energy as 2.45 MeV of detected neutrons supposedly generated due to the fusion of deuterium ions in the lightning discharge channel leads to quantifying the neutron emission flux if the NALD channel distance with respect to the LFGNM setup is established. In this paper we discuss the experiment and the time profiles of several of the large number of the major neutron burst events recorded with LFGNM in association with NALD. Moreover, a rare and an extra-ordinary neutron burst event, in terms of its associated TOF of first detected neutron after triggering, recorded by this system is specifically discussed. In this event, the recorded TOF of 14 μs of the escaping neutron detected by the system immediately after getting triggered by the NALD which struck a nearby tree found located just around 300 meters (physically measured) away from the detector position indicates the energy of the detected neutron $\epsilon_n \approx 2.45$ MeV. In the light of this only event we, therefore, cautiously suggest $^2H(^2H,n)^3He$ deutron-deutron fusion reaction as one of the possible mechanism of the neutron generation co-related with an NALD. Nonetheless, the observations so far have reconfirmed production of neutrons in an NALD.

Keywords: LFGNM, Neutrons corelated with NALD, Cosmic rays

1. Introduction

Lightning is the most commonly experienced geo physical phenomenon on the earth. Since time immemorial humans have been overawed and fascinated by its power and magnificience and consequently has invoked human interest to study this impressive phenomenon. An NALD originates due to thunderstorm activity in which energy of gigantic proportions is involved. One of the channels for the release of this energy is the occurence of an NALD producing electromagnetic spectrum in the form of ultra voilet, infra red, the visible region bands, x-rays [2], gamma ray flashes [3, 4, 5] and, of course, neutrons [1, 6, 7] as well. In the known modern scientific history, Benjamen Franklin is said to have laid the first scientific basis of studying [8] NALD when he demonstrated its electrical nature by conducting the famous kite experiment in 1752. In 1924, C.T.R. Wilson forwarded the hypotheses [9] that the electrons of the atmospheric constituents can be accelerated to very high energies in dense atmospheric layers due to the presence of thunder cloud electric field. These accelerated electrons may lead to the nuclear reactions producing neutrons. Orvile et.al [10] carried out high speed time resolved spectroscopy of the lightning return strokes and suggested lightning flashes can produce a physical state with very high temperature regions that were later conceived to be the hot spots for the thermal neutron production. Subsequently further insights were gained in the phenomenon of thermal neutron production with the help of experimental studies [11] carried out on high voltage discharges of high power (10^{12} W) and short duration ($5\text{x}10^{-8}$s) through thin deuterated polymer fibre when production of 2.45 MeV energy neutrons was revealed. The neutron production in these experiments was attributed to the ${}^{2}H({}^{2}H,n){}^{3}He$ fusion reaction with escaping neutron energy $\epsilon_n \approx 2.45$ MeV. Depending upon the concentration of the deuterium present in these fibres, the neutron yeilds in the range of 10^7 to 10^8 per discharge have been obtained in these experiments. Similarly, in the experiments [12] a discharge of 12 kJ of electrical energy with a short circuit current of 1.91×10^6

A through a deuterated gas is seen to generate a burst of 10^8 to 10^9 neutrons. The production of neutrons in the exploding wire experiments thus confirmed the occurence of nuclear synthesis in such plasmas. Based on these findings [11, 13, 14, 15], it was speculated that neutrons may also be produced in an NALD due to the fusion of deuterium ions naturally present in the atmospheric water vapour. The speculation was based on the premise that during any NALD optimum conditions are available for the plasma formation that may allow certain light weight constituents like deuterium ions to accelerate under the influence of the high electrical field present during the thunderstorms environments and thus induce fusion reactions to release neutrons. In fact, the first estimation of neutron yeild from an NALD was obtained by rescaling the $^2H(^2H,n)^3He$ reaction parameters involved in exploding wire experiments to the NALD. It was postulated [11, 13] that $\approx 10^{15}$ neutrons can be produced by an NALD. On the basis of their results, Libby and Lukens [13] suggested that neutron generation co-related with natural lightning could in fact explain the anomalies in radio-carbon dating. This interesting idea prompted R.L. Fleisher to perform neutron monitoring experiments in association with laboratory discharges that simulated the plasma conditions thought to exist in the lightning channels [14]. However, Fleischer found no evidence for neutron production in these experiments. Again, Fleischer, in an attempt to directly detect neutrons in association with NALD, employed fission track detectors near the lightning arrestors. The measurement of neutron flux in thunder storm environment again yeilded null results. However, on the basis of his findings [15], he set upper limits on the number of neutrons generated by lightning to 4×10^8 thermal neutrons and/or 7×10^{10}, 2.45 MeV neutrons per flash in stark contrast to the value of 10^{15} originally estimated by Libby and Lukens.

Around a decade later in 1985, the first scientific breakthrough for settling the issue of neutron generation in association with NALD was reported by Shah et al [1]. It was the first experimental evidence of observing statistically significant neutron flux enhancement associated with the NALD due to the nearby thunderstorm activity. An ingenious experiment for the detection of neutrons associated with the NALD was conceived and implemented by modifying the configuration of IGY (International Geophysical Year) type neutron monitor[1] operating earlier at the same position for monitoring cosmic ray produced secondary neutrons. The modified experiment is today known as LFGNM [16]. The experiment, in essence, involves a technique of triggering the neutron TOF measurement system by means of sensing and picking up the short term variation in the thunderstorm electrostatic field that coincides with the commencement of the process of the NALD to record the t_d/TOF between the trigger pulse and the first detected neutron believed to be produced in these lightning discharge channels and, then recording the subsequent neutrons in sixty three gates of 20 μs each over a total duration of 1260 μs comparable to the duration of a natural lightning flash. This technique of recording supposedly allows improving manifold the signal to noise ratio of the lightning origin neutrons to the background environmental neutron flux. Thus everytime a significant short time scale (μs duration) electric feild variation is sensed in the proximity of LFGNM environment, a time measurement circuit starts to record the t_d/TOF of the first neutron detected at the detector. The TOF measurement of the first detected neutron after the trigger pulse indirectly facilitates distance measurement of the NALD channel with reference to the detector set up. Therefore, in highly significant events where a large number of neutrons are registered by the system, this line of sight distance is confirmed by physically looking for the damaged object, if any, (particularly nearby tree in the vicinity of the experiment) that has been struck by this particular recorded NALD and comparing it with the emperically calculated distance of the recorded t_d/TOF and assuming the energy of neutrons $\epsilon_n \approx 2.45$ MeV.

Over an observation period of three years upto 1985, Shah et.al [1] registered 11200 natural lightning events with LFGNM operating at HARL, Gulmarg. In 124 of these events 3 or more neutrons were recorded in a time interval of 320 μs (earlier recording time for neutron gates as against the current recording time of 1260 μs of LFGNM). On the basis of the results obtained by means of random manual triggerings, the registering of these 3 or more neutrons in co-relation with the natural lightning trigger was considered as a statistically significant enhancement over the background environmental flux. The average neutron yeild from the results was estimated to range from 10^7 to 10^{10} neutrons per lightning discharge assuming $^2H(^2H,n)^3He$ nuclear reaction with escaping neutron energy $\epsilon_n \approx 2.45$ MeV. At sea level also, Shyam and Kaushik [17] and Kuzhevskij[18] have reported detection of neutron bursts in association with NALD in Mumbai (India) and Moscow (Russia) respectively. Results of these successful experiments were also interpreted as stemming from the $^2H(^2H,n)^3He$ fusion reactions within the NALD channel. However, other contemporary researchers studying the mechanism of the neutron production associated with NALD channels did not substantiate to the fusion process theory for neutron production co-related with natural lightning [19, 20, 21, 22, 23, 24, 25, 26, 27] and instead base their arguments on the speculations of C.T.R Wilson who advanced the idea that acceleration of the charged particles to very high energies, due to the presence of thundercloud electric fields, could lead to a decay or syntheses of atomic nuclei and thus result in the emergence of neutron from NALD channels. They argue that even NALD cannot occur by conventional breakdown process, as is firmly ingrained in the minds, until the electric fields do not reach breakdown value of 3 MVm^{-1} at sea level and through observations the thunderstorm electric fields have been typically found to be only 50-100 KVm^{-1} and on rare occasions it has been found to be $\approx 200KVm^{-1}$ [28]. Therefore, they suggest that nuclear fusion reactions cannot occur to any measurable degree under the electrical conditions prevalent in thunderstorm conditions and that neutrons can instead be generated by means of non-thermal processes like photo nuclear reactions associated with the electrical breakdown driven by runaway electrons as discussed in [24, 28]. Again, they say that the production of neutrons in co-relation with lightning may be actually due to the interaction of the bremstralung radiation with the constituents of the natural lightning discharge channels. The bremstrahlung is supposed to be produced due to the acceleration of electrons in the lightning channel under the influence of high electric field present during the NALD process. The acceleration of the electrons in these discharge channels leads to the break down of the atomic and molecular structure of the constituents into ions and electrons, and electrons being relatively lighter in mass to the ions get highly accelerated and in the process produce more electrons enroute due to the collision with the constituents and leads to relativistic runaway electron avalanche (RREA) process. Therefore in RREA 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. These neutrons possess an energy spectrum which may range from eV to several eVs maximum upto 10 MeV. In fact, evidence has been gathered regarding emission of high energy gamma ray [3, 4] in association with NALD channels. Recently, it has been suggested [18, 29, 30] that these high energy gamma rays originate from a Runaway Breakdown (RB) process in the thunder cloud during lightning discharge. The RB and subsequent lightning discharge process could be initiated by a high energy seed electron produced during a cosmic ray shower. For RB 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.

2. Experimental setup

LFGNM (Figure 1.) is a modified version of the original IGY type cosmic-ray neutron monitor. The lead producer used for multiplicities in standard neutron monitors is completely removed and 28 BF3 counters, each 90 cm long and 3.8 cm in diameter are spread in the form of a pile of surface area of 3x10^4 cm^2. The counters are laid on the surface of 28 cm thick paraffin base and are covered on top by only 8 cm of paraffin caliberated to thermalize 2.45 MeV incident neutrons. This monitor has a background count rate of about

36000 per hour and monitors, round the clock, low energy neutrons produced due to the interaction of cosmic rays with the atmosphere. The observation of these background cosmic ray secondary neutrons forms a different kind of study in itself and important results, on short term and long term modulation effects of cosmic rays, obtained so far by studying its data are reported in [31, 32]

LFGNM is integrated with the redesigned electronic system for recording neutrons for a time interval of several hundred μs following the sensing of a lightning discharge. Moreover, a multi-stroke lightning circuit is used for recording differential times between the successive strokes of a multi-stroke lightning flash. The system is activated when an antenna placed near LFGNM senses in the ambient atmosphere the variation in the electrostatic field associated with the commencement of an NALD. The detector senses this electrostatic field variation almost instantaneously compared to the time taken by a 2.45 MeV lightning generated neutrons that escapes the scattering of constituent nuclei of the atmosphere and reach to the detector. The t_d/TOF 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 neutron producing natural lightning channel. This neutron time-delay, with a 1 μs time resolution, is recorded electronically in six hex counters [74LS393] organized as six-digit hex-cache. Thereafter, the subsequent 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 neutron counting gates consecutively in retriggering mode [33]. The gate-width is continuously adjustable from 5 to 75 μs. However, presently the gate-width is prefixed at 20 μs enabling the system to have a total neutron recording time of 1260 μs. 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 the duration of all the the sixty-three neutron-counting gates i.e. 1260 μs is over, the whole system closes. Subsequently, the data from the RAM is transferred to the PC through RS232 serial interface and the RAM is rewritten with zeros. The system now remains ready for recording the next event.

3. Results and Discussion

During the observational period from year 2006 to 2009 LFGNM trigerred 150 times due to the NALDs occurring in its proximity. In each of these events more than two neutrons were recorded in 1260 μs time interval which starts just after the elapse of the t_d/TOF of the first detected neutron af-

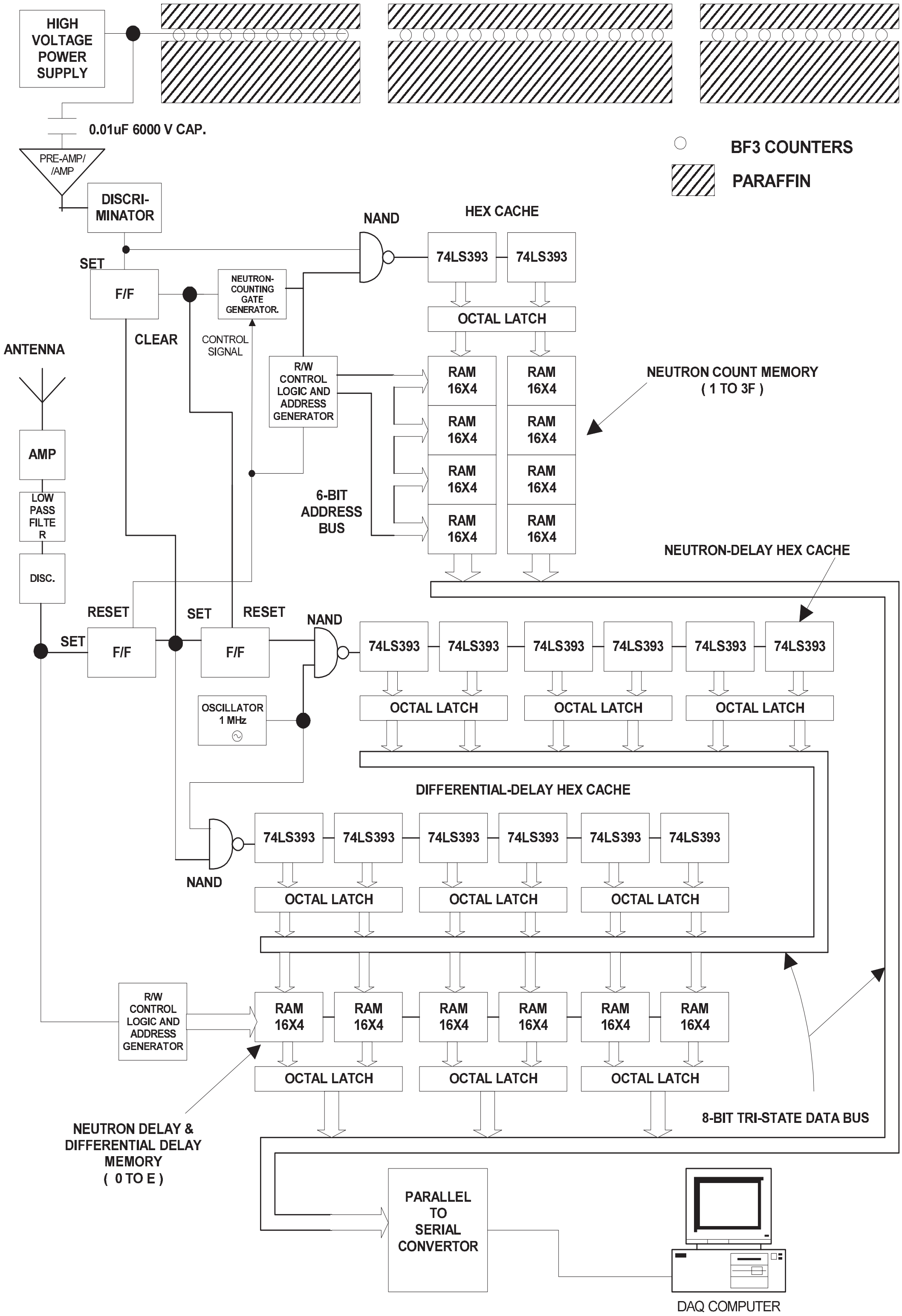

Figure 1: Block diagram of lightning neutron detection system

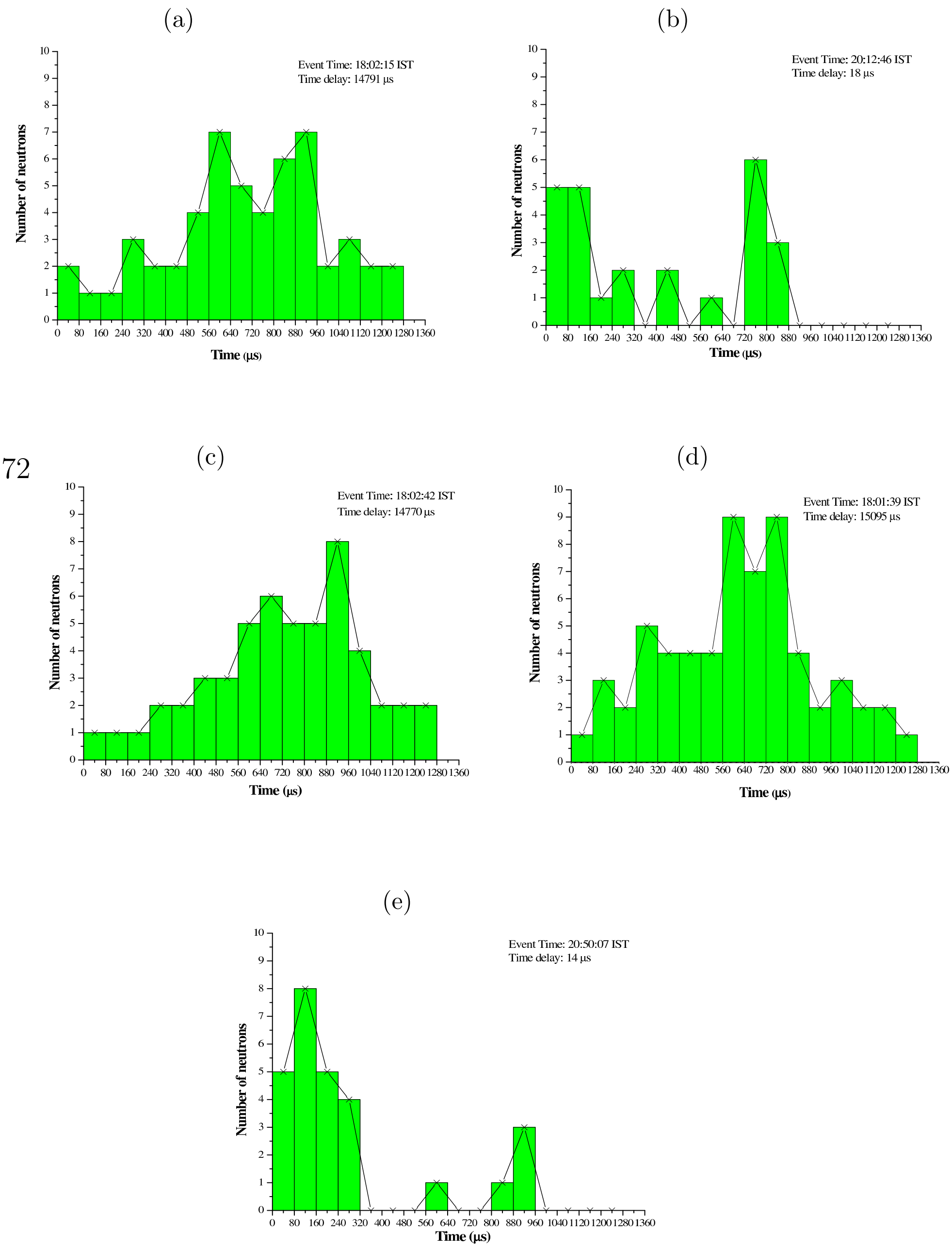

Figure 2: Time profiles of neutron detected during NALD

ter LFGNM trigerring. However, in Table 1, we have shown only 20 of these events. These represent the events which have recorded $\geqq 4$ neutrons in 1260 μs recording time interval. Besides the table shows the corresponding event date, event time, delay time and the total number of neutrons recorded in these events. As shown in the table we observe a wide distribution of the t_D/TOF of the detected neutrons. For example corresponding to the event date 26/10/2009 and time 11:00:57 (IST) a delay time of 1 μs is recorded with the detection of 30 neutrons in 1260 μs. Similarly, corresponding to the event dated 13/06/2009 and time 13:14:03 (IST) the delay time of 226676 μs is recorded with the detection of 19 neutrons in the same time interval. However, on the basis of the analyses of the wide distribution of time delays in all these events no conclusive information is obtained about the distance between the trigerring source and the LFGNM setup. While as the recording of tens of μs time delay in the events points towards the occurrence of lightning discharges just hundreds of meters away from LFGNM setup, at the same time delay times of hundreds of μs observed in some other events points towards the occurrence of lightning discharges to be tens of kilometers away. Considering the neutron source distance of tens of kilometers away in the other events will not lead to any neutron detection in LFGNM setup. So this kind of anomaly in the recorded time delays is inexplicable.

However, during May and June of the year 2006, major thunderstorm activity occurred in the vicinity of LFGNM. The system triggered sixty times by NALD during this period. Out of these 60 triggering 50 events recorded $\geqq$ 4 neutrons per event in 1260 μs. We show here the plots of only five of these 50 events, in subfigures (a)-(e) of figure 2, where more than twenty neutrons have been recorded in each event. Each point on these graphs depicts the number of detected neutrons grouped into consecutive time intervals of 80 μs for the total neutron recording time interval of 1260 μs. As illustrated, the subfigure (a) shows a single-stroke event and has recorded 63 neutrons with a time delay of 14791 μs. The subfigure (b) shows a two-stroke event and has recorded 24 neutrons with recorded time delay of the first detected neutron after triggering the system as 18 μs. The subfigure (c) shows a two-stroke event and has recorded 50 neutrons with a time delay of 14770 μs. 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 μs subfigure (d). However, the event shown in subfigure (e) recorded on 01/05/06 at 20:50:07 (IST) is the most significant as it was recorded at the time of a lightning strike to a tree located $\sim$ 300 m away from the detector. On spot inspection, the tree was seen to be substantially damaged due to the lightning strike and the distance between the tree and LFGNM was established to be 300 m by physical measurement. In aggregate, twenty-seven neutrons were detected in the total recording time interval of 1260 μs in this single-stroke lightning event. After the system was triggered by this lightning strike, the 14 μs recorded t_d/TOF of the first detected neutron by LFGNM places its source at a distance of 296 m (almost equal to the physically measured distance of 300 m) away from the detector on the basis of the emperical distance calculation formula 'd' derived from the kinetic energy relation given by :

$$d = 13.5 \times 10^6 \times \Delta t \times \sqrt{E} \tag{1}$$

where E , equivalent to 2.45 MeV, is the energy of the neutron and

'Δt' is the observed t_d/TOF of the first detected neutron in microseconds. Thus, it seems that the neutrons recorded by our system were produced in this lightning discharge and the energy of these neutrons $\epsilon_n \approx 2.45$ MeV. However, we have not been able to observe such a kind of an event again in our observation where the empirically calculated neutron traversed distance derived by using the recorded t_d/TOF could be counterchecked/verified with the corresponding distance measurement of the damaged object with respect to the detector set up. Since none of the other recorded NALD has struck on any nearby object to LFGNM. In other major events,recorded by LFGNM during the observation period, the neutron t_d/TOF are invariably in tens to hundreds of millisecond in range, thus indicating that either the detected neutrons of 2.45 MeV energy origin first undergo energy degradation due to the multiple scattering with the constituents of the intervening atmosphere before being detected by the system or the incident energy of these detected neutrons may be far less than the assumed 2.45 MeV energy, which points that these detected neutron may not originate from the described fusion process. However, a different kind of a process may be responsible for the neutron generation in co-relation with the NALD. The uncertainity in finding exact energy of these neutrons can be resolved by incorporating a neutron energy spectroscopic system with LFGNM that would measure the incident energy of the neutrons co-related with the NALD. However, devising and incorporating such a setup is both difficult and beyond our current resources.

4. Conclusion

We confirm the production of neutrons in co-relation with natural atmospheric lightning discharges. The analysis of the one of the major events of the data obtained with LFGNM has revealed the energy of the neutron corelated with natural atmospheric lightning exactly towards 2.45 MeV. Therefore, the hypothesis that the neutron generation in these lightning discharges due to the process of $^2H(^2H, n)^3He$ fusion reaction may not be invalid.

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The data used in this study can be made available on request from Head Physics Group, Nuclear Resaerch Laboratory, BARC, Srinagar, Kashmir E-mail: pishtiaq@gmail.com.

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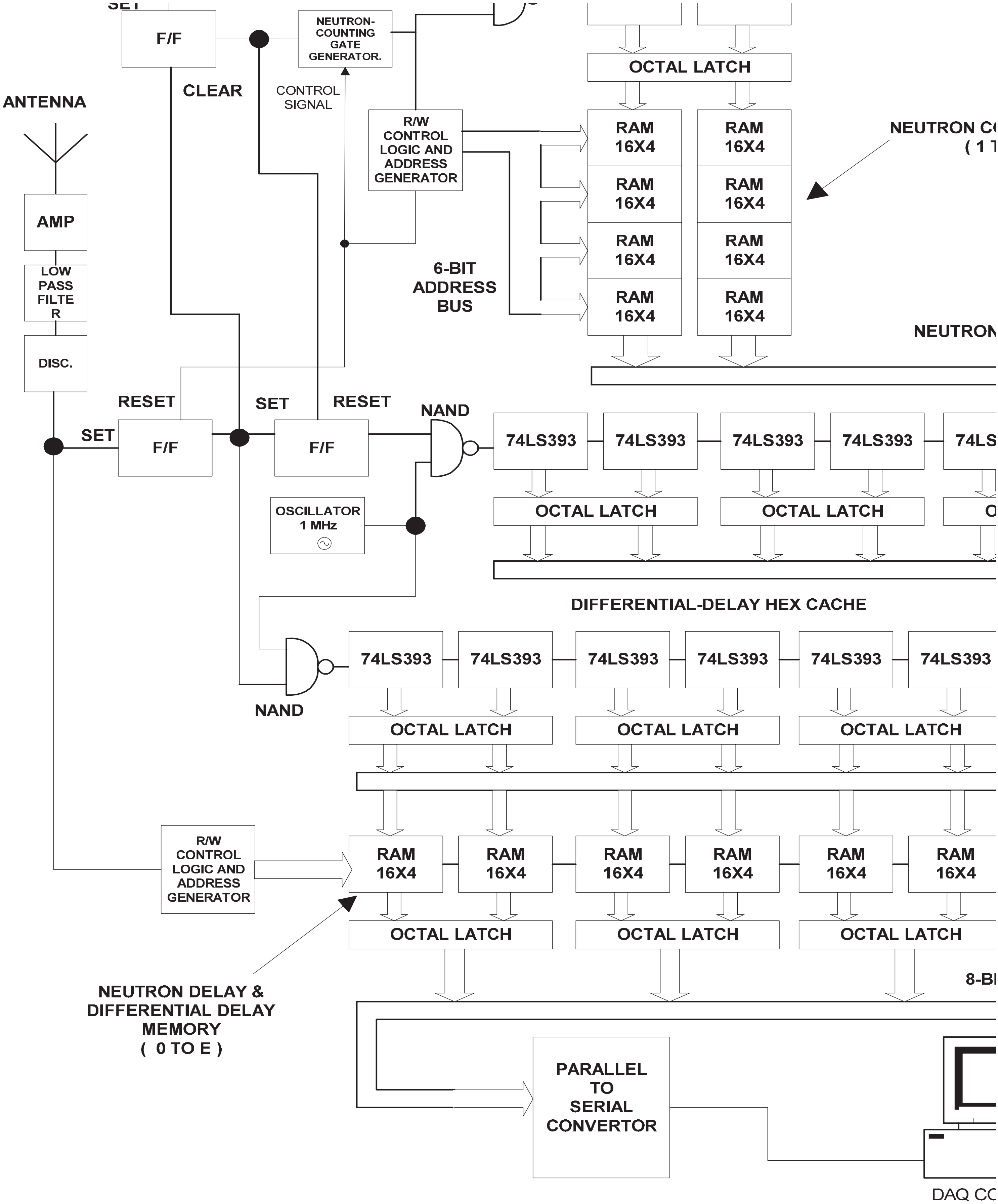
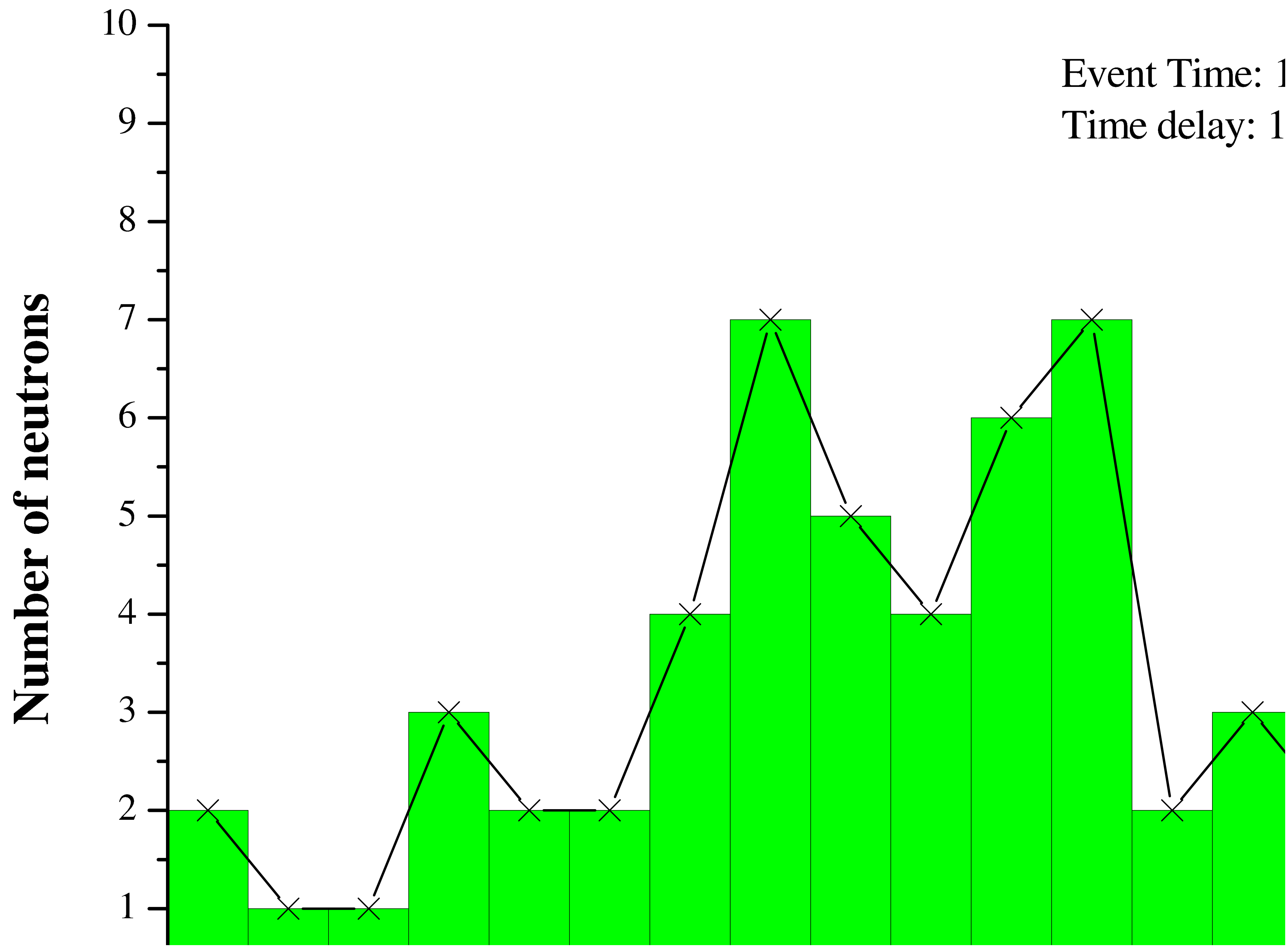
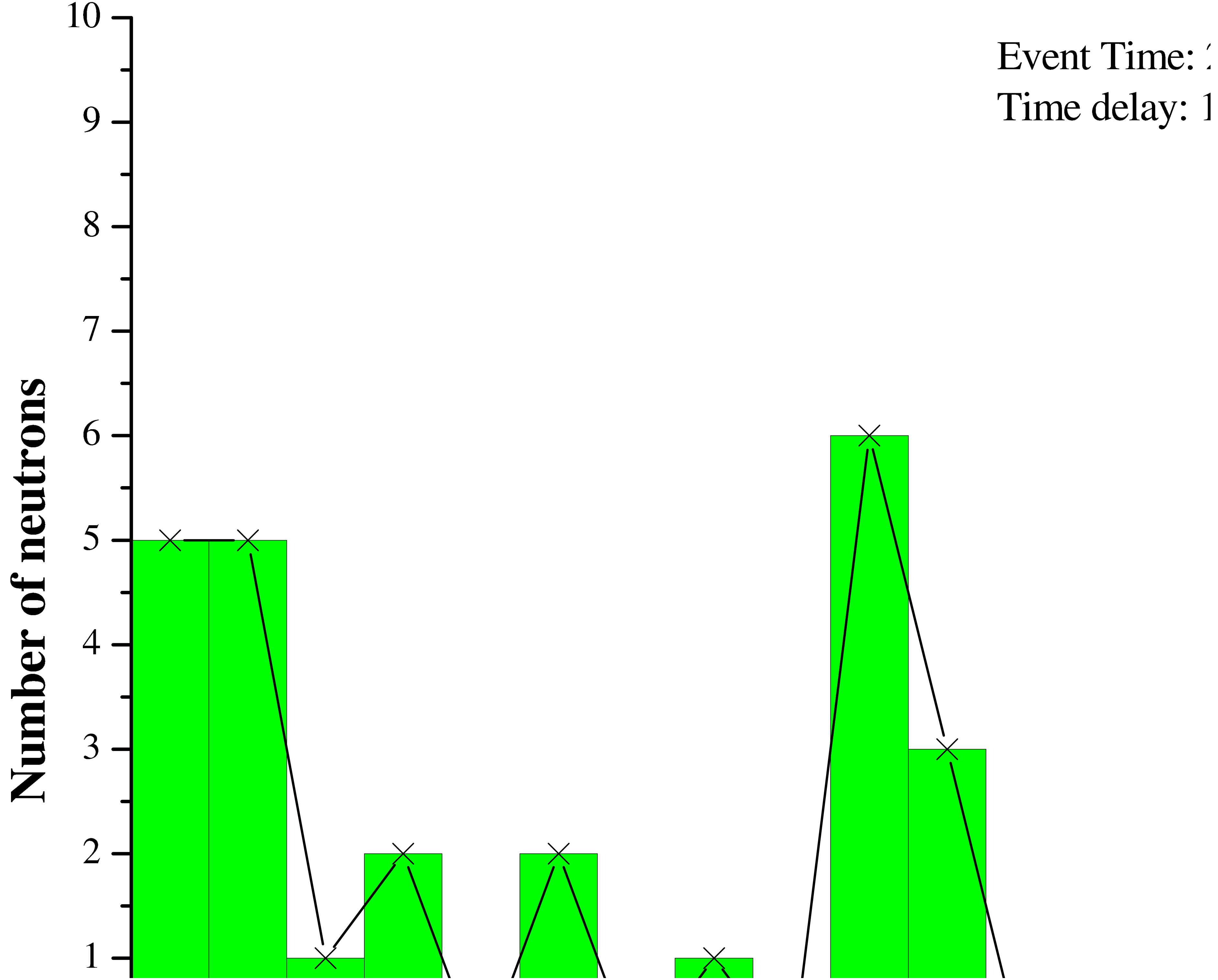
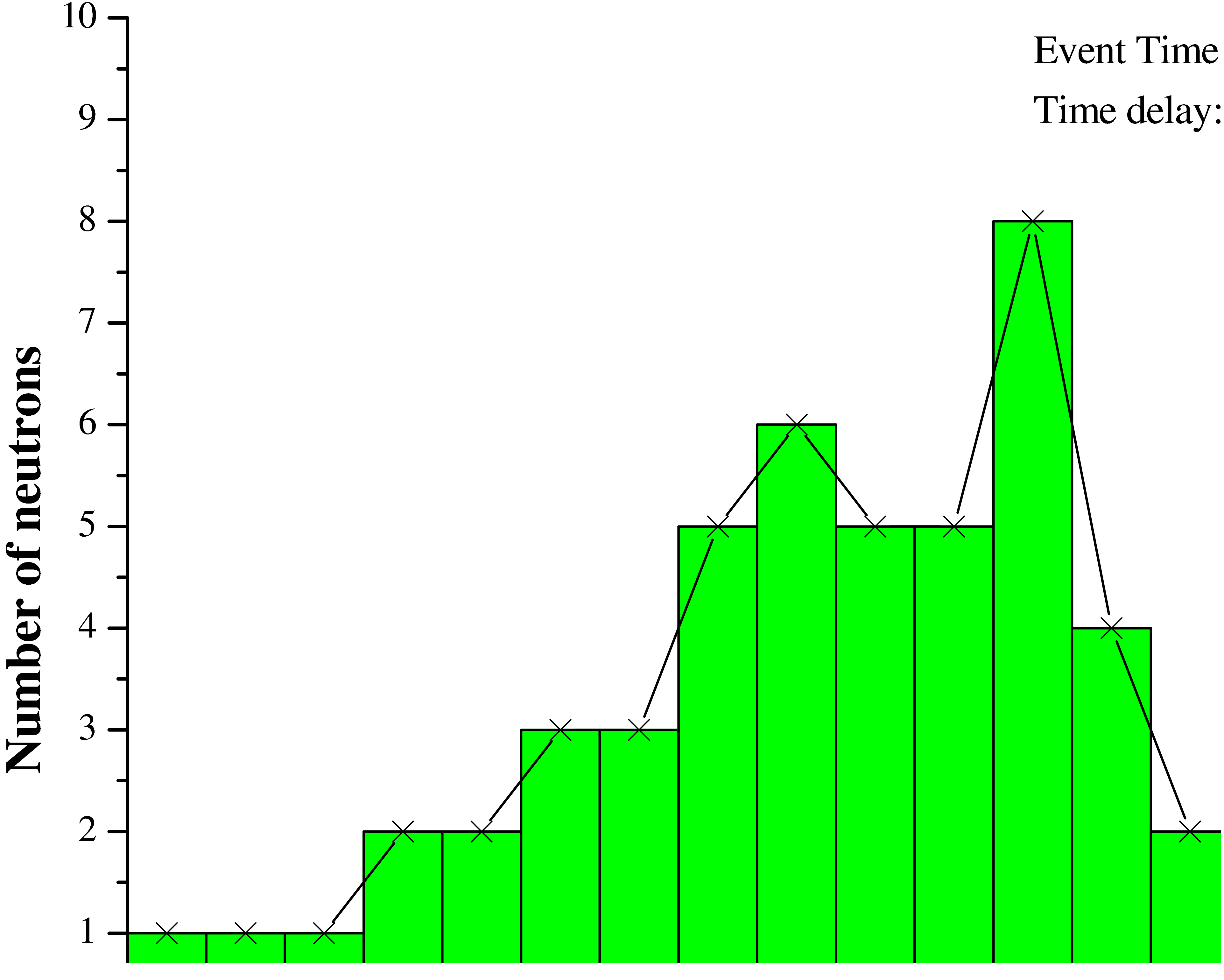
Event Date	Event Time (IST)	Delay Time/TOF (μs)	Total neutrons detected
1/5/2006	18:01:39	15095	63
1/5/2006	18:02:15	14791	53
1/5/2006	18:02:42	14770	50
1/5/2006	20:12:46	18	24
1/5/2006	20:50:07	14	27
13/8/2007	10:47:43	31	13
13/8/2007	10:49:56	40	52
27/7/2007	11:02:32	15094	42
19/4/2008	17:20:28	7040	5
2/4/2009	22:23:39	57729	18
3/4/2009	02:05:0727	311	5
2/5/2009	15:52:10	83246	5
8/6/2009	10:49:44	59	19
13/6/2009	13:14:03	226676	19
13/6/2009	14:07:21	9	17
13/6/2009	15:14:43	6279	4
12/7/2009	20:48:24	40104	9
26/7/2009	20:27:49	180124	6
24/8/2009	19:45:37	38	6
26/10/2009	11:00:57	1	30

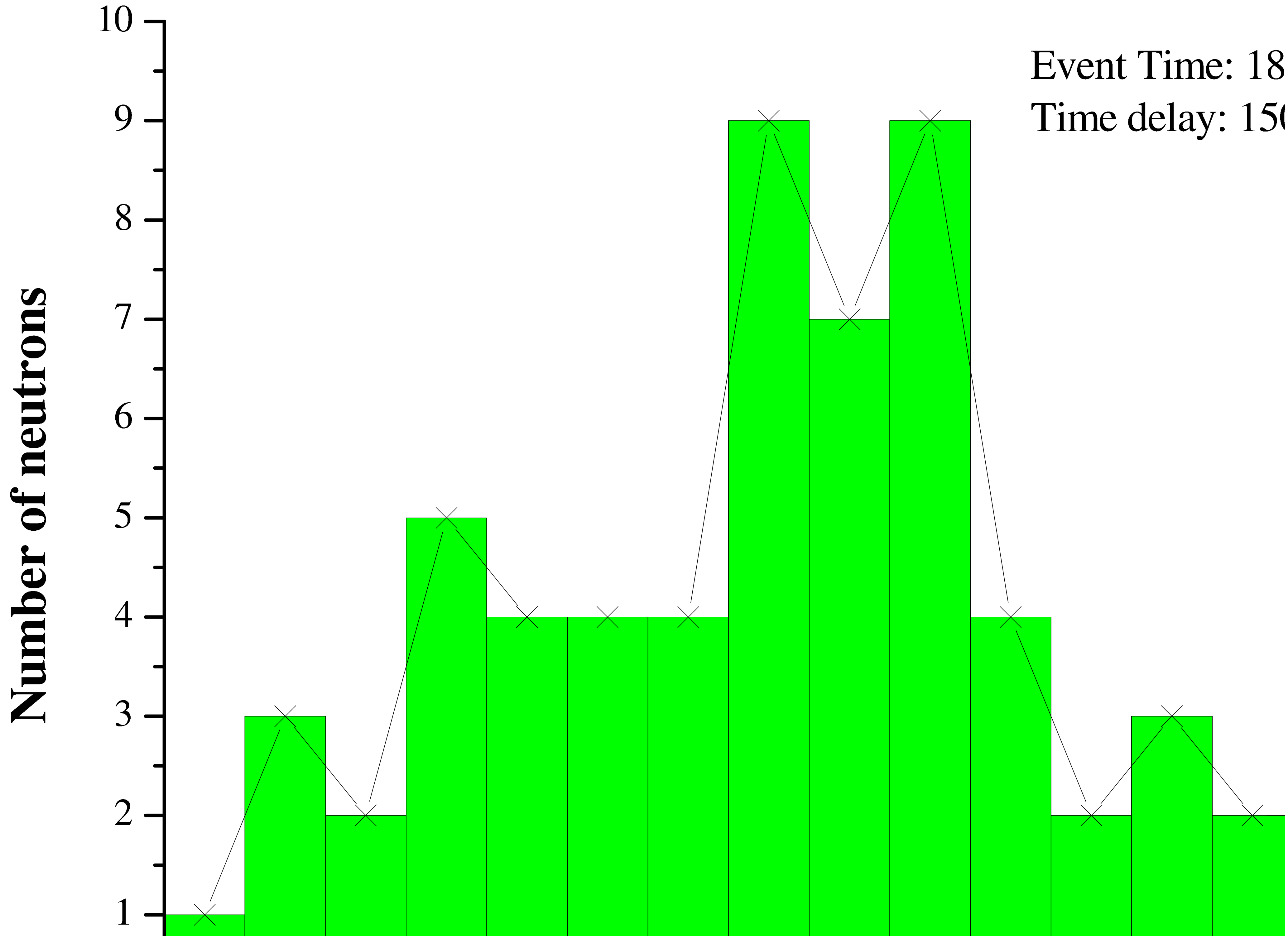
Table 1: **Neutrons detected in 1260 μs**


SET
F/F
NEUTRON-COUNTING GATE GENERATOR.
CLEAR
CONTROL SIGNAL
ANTENNA
R/W CONTROL LOGIC AND ADDRESS GENERATOR
OCTAL LATCH
RAM 16X4
NEUTRON C
(1 T
AMP
LOW PASS FILTE R
6-BIT ADDRESS BUS
NEUTRON
DISC.
RESET
SET
RESET
NAND
SET
F/F
F/F
74LS393
74LS393
74LS393
74LS393
74LS
OSCILLATOR 1 MHz
OCTAL LATCH
OCTAL LATCH
O
DIFFERENTIAL-DELAY HEX CACHE
74LS393
NAND
OCTAL LATCH
R/W CONTROL LOGIC AND ADDRESS GENERATOR
RAM 16X4
NEUTRON DELAY & DIFFERENTIAL DELAY MEMORY (0 TO E)
8-BI
PARALLEL TO SERIAL CONVERTOR
DAQ CO

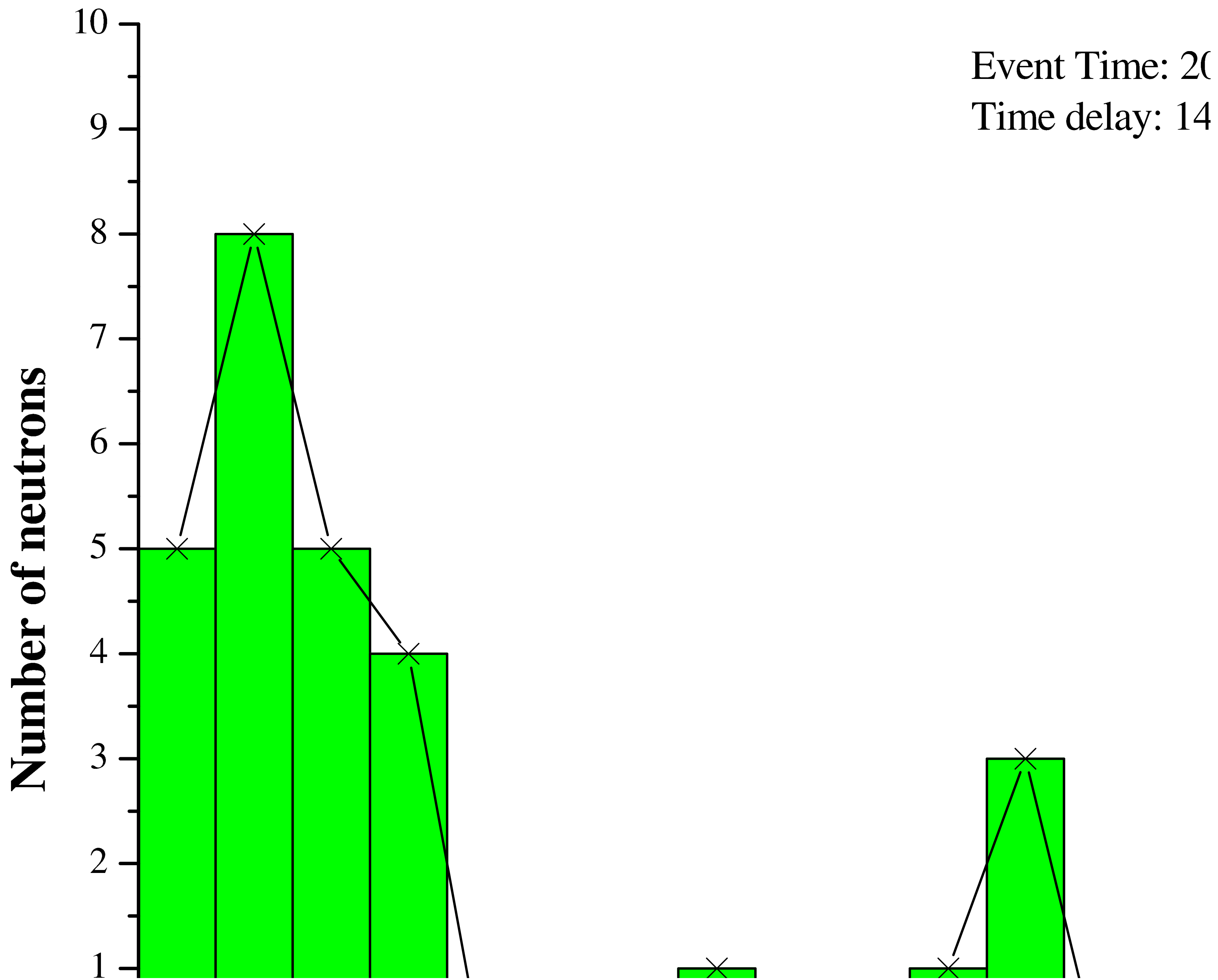

Event Time: 1
Time delay: 1
Number of neutrons
10
9
8
7
6
5
4
3
2
1


Event Time: :
Time delay: 1
Number of neutrons
10
9
8
7
6
5
4
3
2
1


Event Time
Time delay:
Number of neutrons
10
9
8
7
6
5
4
3
2
1



Number of neutrons
10
9
8
7
6
5
4
3
2
1
Event Time: 18
Time delay: 15


Number of neutrons
10
9
8
7
6
5
4
3
2
1
Event Time: 2(
Time delay: 14