

## SEARCH FOR «NEUTRON BURSTS» WITH MEXICO CITY NEUTRON MONITOR

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### ABSTRACT

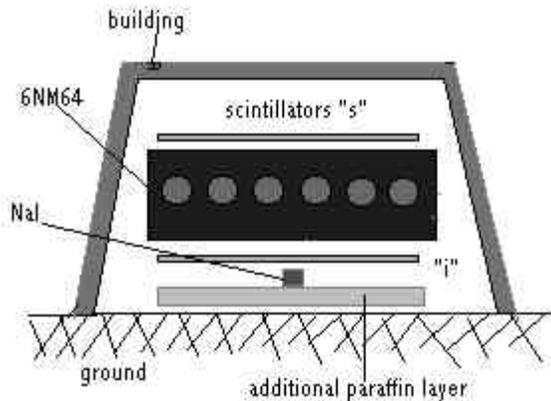
A search was made for abnormal high multiplicity neutron events, with the combined array of a 6NM64 neutron supermonitor and 8 plastic scintillators installed in Mexico City. Some evidences were presented in the last years for such events[1,2], but their existence was not established beyond any doubt nor the conditions under which they occur. Our results show existence of very high multiplicity events in coincidence with high counting rates of the plastic scintillators during several msec, when Extensive Air Showers size is high enough. A detailed consideration of the experiment and data on the multiplicities as well as the temporal distributions of the pulses are presented. The explanation of the peculiar time distributions of such events lies in neutron physics known processes and not in new physics phenomena as claimed in [2].

**Introduction.** In the last years, there appeared evidences [1, 2] for the existence of abnormal large events in a neutron monitor (NM) which we shall call *neutron bursts*. Many standard neutron monitors are running throughout the world but only one of them reported about such events. The explanation can be find out if one takes into account that experiments of such a type are absolutely out of the frames of normal NM use: cosmic ray intensity variations at low energy. Accumulation time of counts in standard NM is usually several minutes, that is too large to see *bursts* with a characteristic time of several msec. Therefore, special arrangement is necessary.

**Experiment.** With the aim to detect *neutron bursts* we performed an experiment using the Mexico City 6NM64 and associated muon telescope, consisting of 8 plastic scintillator counters of 100x100x5 cm<sup>3</sup> each, located just above and below the NM (see Fig.1). The use of the scintillator counters plays a crucial role in the experiment (see below). The signals from upper 4 counters were added and designated detector «s». Likewise the 4 lower counters constituted detector «i». In addition a NaI scintillator (Ø10cm x 10cm) was used as a detector for gammas and for triggering. These 3 signals and 1signal from NM (first differentiated sum of all 6 boron counters, then only from one of them without differentiation) were put to 4 channels of a

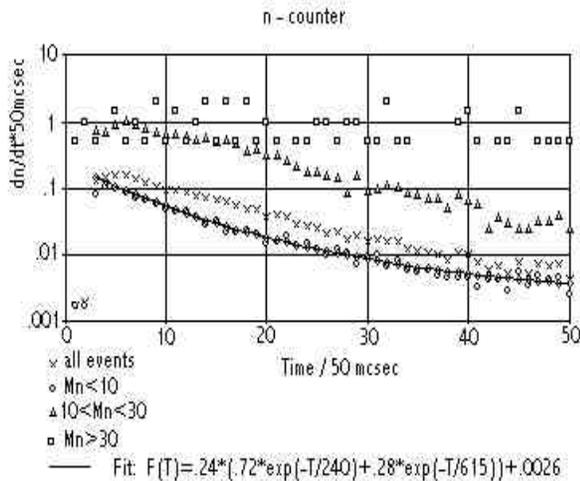
digital oscilloscope TDS420A which was the main instrumng in a data acquisition system connected to a PC. We stored full screen pictures for a time of 2500 µsec, with step of 1 µsec. Thus, we had 2500 points per channel, and 10 Kb per 1 event.

Several triggers were used during the experiment but here we present data obtained with one of them, namely 5-fold coincidence of 4 «i» detectors (under Pb of NM) and NaI detector with a threshold of 25 Mev situated in the centre under the NM; For each trigger we have 2 sets of data: with and without a layer of 12.5 cm thickness x 5.7 m<sup>2</sup> area of paraffin, located on the ground below the NM.

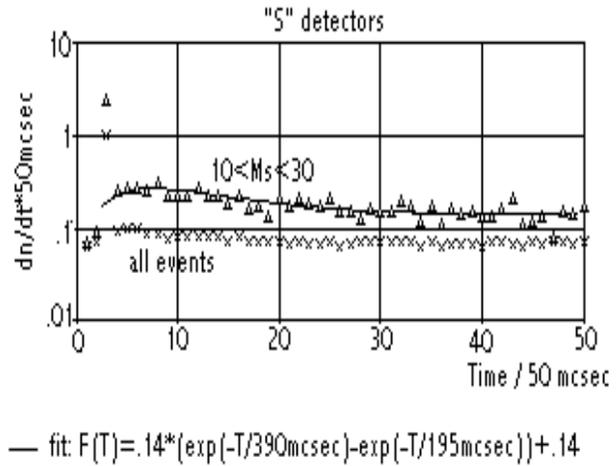


**Fig.1. Schematic view of Mexico City 6NM64 monitor and experimental set-up.**

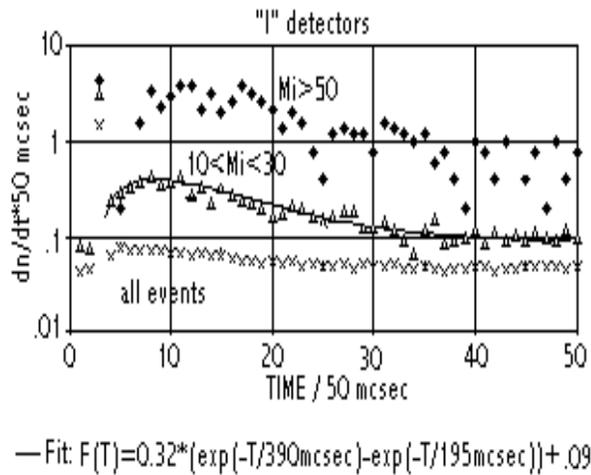
**Results.** Fig.2 shows time distributions for a neutron counter for selected ranges of multiplicities  $M_n$ . The standard function  $F(t)=C \cdot (\exp(-t/240\mu\text{sec}) + \exp(-t/615\mu\text{sec})) + bg$ , where  $C=0.24$  and  $bg=0.0026$  is a background, fitted for  $M_n < 10$  is also shown. With additional paraffin layer  $C=0.30$  and  $bg=0.0026$ . This function fits our data well but only for low multiplicities  $M_n < 10$ . Data for higher  $M_n$  are very similar to those obtained in [2]. Our data correspond to 1 boron counter and our bin width is  $50 \mu\text{sec}$ , while in [2] data correspond to 6 counters and bin width is  $1 \mu\text{sec}$ . The behaviour of our data shown in fig. 2 can be explained



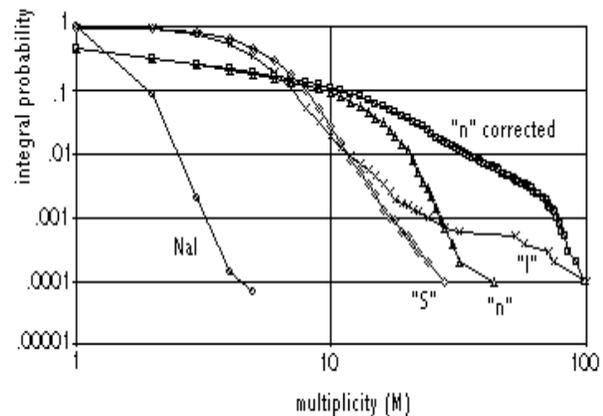
**Fig. 2. Time distributions for n counters**



**Fig.3. Time distributions for <s> detector**



**Fig. 4. Time distributions for <i> detectors.**



**Fig.5. Multiplicity spectra for different detectors.**

in terms of known neutron physics processes as we shall see below.

Fig. 3 and fig. 4 show the same distributions but for <s> and <i> detectors. The multiplicities in these detectors sometimes are very high while the mean value due to chance coincidences is about 3. Fig. 5 shows observed multiplicity spectra for different detectors. Our data for outer detectors is similar to that given in [2]. So our experimental data confirm the results of [1, 2], however our interpretation of the data is different.

**Analysis.** Returning to fig. 2, one can see that the maximum counting rate for the highest  $M_n$  is close to 2 per bin. This is precisely our counting rate upper limit since a pulse width from boron counter (BP 28) standard discriminator is equal to  $20\text{-}25 \mu\text{sec}$ . Within a bin width of  $50 \mu\text{sec}$  the counts can not exceed 2.

This limit exists for any standard NM64 as the leading front of a proportional counter pulse is  $\sim 10 \mu\text{sec}$  and its dead (and recovery) time is even higher [5]. Furthermore, due to Poissonian distribution of counts inside each bin, time intervals between 2 pulses are distributed as  $n_i \exp(-t n_i) dt$ , where  $n_i$  is a counting rate mathematical expectation in a particular bin  $i$  of width  $dt$ . The probability that no pulse will be missed due to dead time  $t_d$  is also exponential:  $\exp(-t_d n_i)$  and is not negligible even for  $t_d n_i < 0.1$ . So the bigger expectations – the bigger difference between that and measured number. This results in a flattening of time distributions for high  $M_n$  even at  $n_i \ll 2/50 \mu\text{sec}$  where  $t_d n_i \ll 1$ . One should also take into account that expectations  $n_i$  are distributed exponentially (see fit) and the first bins reach this region very quickly. An advantage of our experiment is full oscilloscope screen control. Thanks to this we can see events where pulse width from the boron counter is  $> 1.6 \text{ msec}$ . This was really a burst of unresolved pulses while a scaler will count it as only 1. The main issue here is the recovery time of proportional counter. A sharp differentiation at discriminator input can be made but this does not mean that resolving time for burst of pulses will be  $< 1 \mu\text{sec}$  as the recovery time of gas counters is additive and can be as large as  $100 \mu\text{sec}$  [5]. In fig. 5 we show for  $n$  counter 2 multiplicity spectra. We attempted a correction simply dividing pulse widths by  $20 \mu\text{sec}$ ; this is not a full correction since real intensity is much higher.

Therefore, observed time distributions for  $n$  counters are just what one can expect taking into account dead time and lost counts. The observed flattening is caused by poor time resolution of proportional counters. This explains why in [2] authors had similar behaviour for big boron counters and for small helium ones. As they really made short pulses ( $1 \mu\text{s}$ ) using sharp differentiation on discriminators inputs [3], their counting limit is  $1 \mu\text{s}^{-1}$  just what they have in their plots. Increase of counts vs time can be explained by long recovery time of gas counters, which increases with gas pressure and should be higher for helium counters.

The time distributions for «s» and «i» detectors shown in fig. 3 and fig.4 really reveal some interesting physics. These detectors are very fast compared to  $n$  counters. In our case their time resolution depends only on discriminator output pulse width. We made it equal to  $1.5 \mu\text{sec}$  to exclude a possibility of lost pulses since the oscilloscope digitising step was equal to  $1 \mu\text{sec}$ . As intensities for these detectors are low the time resolution is not a problem here and we are sure that all obtained distributions have no saturation effects. Nevertheless, all of them are also rather flat and have maxima. One may be tempted to interpret this as an existence of a delayed shower component as it was done in [1, 2]. However, looking more carefully one can see that the probability to see these delayed pulses is higher for lower «i» detectors. Therefore, these pulses are not produced by EAS particles. More probably they are produced by  $n$ 's scattered back from ground (albedo  $n$ 's), because: i) organic scintillator detectors are sensitive to fast  $n$ 's due to recoil  $p$ ; ii) no other particle could live long enough in matter, to move in upward direction and to have energy above our threshold  $4 \text{ MeV}$ ; iii) additional paraffin layer removes the highest  $M_i$  increases a little bit  $M_s$  and data for «i» and «s» became almost identical.

One could argue that the delayed pulses were caused by decays of unstable nuclides produced by shower particles. Yes, this process also adds some pulses, but only as a flat background increasing with event multiplicity. Decay processes follow exponential distributions and can not produce maxima in time but at  $t=0$ . One possible candidate for such process is a capture of stopped  $\pi^-$  and  $\mu^-$  by  $C^{12}$  nuclei results in  $B^{12}$  nuclei, with a half-life time of  $20 \text{ msec}$  and decay releasing an energy of  $13.4 \text{ MeV}$ . Note that plastic scintillator consists mostly (by weight) of carbon  $C^{12}$  and NM moderator is similar material (polyethylene).

The main effect of delayed pulses is produced by fast  $n$ 's ( $> 4 \text{ MeV}$  in our case). When EAS core enters the ground, it produces many  $n$ 's. As the effective area of shower is much bigger than that of NM, thickness of NM is only  $\sim 0.75$  of inelastic interaction length and  $n$  production rate per gram depends on atomic number as  $A^{0.4}$  [4], most of the  $n$ 's are produced outside the NM. Moreover, most of the fast  $n$ 's generated in Pb, escape moderator during the first few  $\mu\text{sec}$  and come to the ground. It is well known that fast  $n$ 's have very long range in heavy materials, as scattering cross section is  $s_{sc} \sim 1/v$  and in each collision they lose in average a fraction of energy  $dE = (4/3) \times m_n \times M_N / (M_N + m_n)^2$ , where  $M_N$  is nucleus mass, and  $m_n$  is neutron mass. Let us estimate the time needed for  $n$  thermalization in standard rock consisting of  $\text{SiO}_2$ . In

NM moderator  $n$  needs  $\sim 20$  collisions with  $p$  to be thermalized and the characteristic time of this process is equal to  $t_p = 13.5 \mu\text{sec}$  [4]. In rock  $n$  must be scattered  $\sim 270$  times before thermalization. Then taking into account the differences in cross sections (4.2b for  $n$ -O scattering instead of 38b for  $n$ -p) one can expect  $t_{\text{SiO}_2} \sim 2 \text{ msec}$ . To work as a moderator, matter should have small cross section for absorption and high for scattering. For both rock elements (Si and O)  $s_{sc} \gg s_{abs}$ . Therefore, rock can work as a moderator, but with rather small efficiency in time ( $t_{\text{rock}}$  can vary in a wide range due to sensitivity to a ground water level). Moreover, this process produces maxima in time distributions because probability for  $n$  to reach the detector at time  $t$  is  $p1 = 1 - \exp(-t/t_{\text{rock}})$  and  $p2 = \exp(-t/t_{\text{rock}})$  is a probability for  $n$  to survive with energy above 4 MeV. Then the probability to reach the detector and to produce a pulse above threshold at time  $t$  is  $P(t) = p1 * p2 = \exp(-t/t_{\text{rock}}) - \exp(-2t/t_{\text{rock}})$ . This function has a maximum at  $t = -t_{\text{rock}} * \ln(1/2)$ . Our data for «i» detectors can be fitted rather good for any multiplicity  $M_i$  by functions  $F(t) = C(\exp(-t/t) - \exp(-2t/t)) + bg$ , where  $C = C(M)$  and is constant in time, and  $bg = bg(M)$  is a background that also increases when  $M$  increases due to induced radioactivity mentioned above. From our data we estimate  $t_{\text{rock}} \sim 400 \mu\text{sec}$  (in dry season). This time is less than  $t_{\text{SiO}_2}$  because we detected partly moderated  $n$ 's still having energy  $> 4 \text{ MeV}$ .

To register an induced radioactivity (mainly  $g$  we had a NaI detector. With a small efficiency, corresponding to its small area it also detected delayed pulses of energy 4 - 5 MeV. Time distribution of these pulses follows that for plastic scintillators. This means that they are also caused by  $n$ 's. NaI is not sensitive to  $n$ 's but it is sensitive to reactions caused by  $n$ 's. In our opinion this could be reaction of  $n$  absorption by  $I^{127}$ , whose cross section (6.2b for thermal  $n$  and 140b including resonances in range 20-200 eV) is rather high as well as by  $Na^{23}$  ( $s_{abs} = 0.5b$ ). New nuclei are usually produced in excited state and emit one or more  $g$ 's (( $n, g$  reactions) being detected by NaI detector. Both these elements are known as a target in neutron activation type detectors [5]. Decays of other unstable nuclides can also be detected.

Montecarlo simulations made for the experiment showed that our effective threshold for primaries is  $\sim 10^{14} \text{ eV}$ , the most probable  $Ne = 2 \cdot 10^4$  and the most probable core distance is 3 m. Our trigger rate was  $\sim 0.5 \text{ min}^{-1}$  but high multiplicity events rate is  $\sim 1 \text{ day}^{-1}$ . This proves that *neutron bursts* are caused by EAS having size much higher than our threshold.

**Conclusion.** Our experiment has confirmed the existence of *neutron bursts*. After recalculation using only the tails of distributions in fig. 2 and assuming its standard shapes we estimated that the real number of  $n$ 's absorbed by boron in 6NM64 is  $> 1500$  in the measured range  $30 < M_n < 50$  and  $> 16000$  in the biggest event. Therefore we have detected the same events as in [1,2] but we do not confirm the existence of EAS particles delayed by as long as a few msec.

We have observed several interesting effects that known neutron physics processes can explain satisfactorily. We can also add that the Mexico City neutron monitor 6NM64 together with a muon telescope is very convenient instrument for experiments of such a type. The only disadvantage is a lack of EAS array nearby, but the latter can be made in the future.

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