Using a Neutron detector in SonoLuminescence Experiment - Part I
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D. Shapira[1], M. Saltmarsh[2], R. Varner[1] and T.A Lewis[3]
[1]Physics Division Oak Ridge National Lab. Oak Ridge, TN 37830
[2]Physics Department University of Tennessee, Knoxville TN.
[3]Instrum. and Controls Division Oak Ridge National Lab. Oak Ridge, TN 37830

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1 Introduction

A recent series of experiments conducted by Taleyarkhan et. al.in the Engineering Technology Division has reportedly produced evidence for the emission of "penetrating radiation" in coincidence with light (sonoluminescence) from the collapse of bubbles in Deuterated acetone. The original coincidence experiments were based the observation of concurrent flashes from a light detector (PM tube) and signals from a plastic scintillator + PM tube as viewed on a digital sampling oscilloscope.

An ad hoc review of the experiment concluded that the experiment should be repeated using more sophisticated detection and data acquisition equipment. In particular a liquid scintillator based detector would provide the capability for n-γ discrimination, and multi parameter data acquisition capability would allow better characterization of the detected events. Such equipment was readily available from the Physics Division, as was the necessary expertise to use it.

Table 1 gives the chronology of evaluation experiments performed by the original authors with the help of Physics Division personnel.

Date	Activity
June 8	Agreed to provide Rusi with the neutron detector.
June 10	Detector and electronics assembled and ready to ship.
June 12	Meet with Rusi and Colleen: show detector capabilities.
June 14	It was decided that physics not provide only the detector but also a multi parameter data acquisition system.
June 18	Data Acquisition and neutron detector brought to ETD, set up and tested with a Pu/Be and the neutron generator sources.
June 19	Characterize the background γ and neutron spectra.
June 20	Study relation of detector flash to neutron generator pulse
June 21	Continue the same. Start setup for SL-n/γ coincidences.
June 22	Modified the data acquisition to record SL and neutron coincidences. Try a first run with Deuterated Acetone.
June 23	Fix blocking signal to ensure blocking of n/γ detector during neutron generator pulse on time.
June 25	Run experiments, with and without cavitation and with and without blocking during the neutron generator on cycle.
June 26	Start data analysis - no clear signal for coincidences.
July 3	Try to work on improvements - increase coincidence time to 20μs.
July 5	PMT tube in nγ detector went bad.
July 13	Set up for experiment with coincidence plus singles events . Set up 1MHz counter to time events relative to PNG trigger.
July 24	Final data run with all in place.

Table 1: **Summary of events.**

2 The neutron detector

The neutron detector is a unit originally made as a part of the HHIRF spin spectrometer. It has a pentagonal shaped container housing the liquid scintillator (NE213) viewed by a PM tube with a 5" diameter photo cathode. Conventional n-γ discrimination is accomplished via pulse shape analysis based on the time difference between a prompt signal and a slower cross over time from the double differentiated light output. A block diagram of the electronics setup is shown in Fig. 1.

A two dimensional plot of cross over time versus signal amplitude obtained with a Pu/Be source is shown in Fig. 2. Excellent separation between neutrons and gammas is obtained.

3 Possible sources of background in the experiment

There are several sources of background which must be measured to evaluate how many of the recorded events in any experiment are due to random coincidences between essentially unrelated signals.

The following list the signals that are available from each detector

1. Neutron Gamma detector (plastic or liquid scintillator)
    (a) There is a continuous background, with no associated time structure, due to various radiation in and around the ETD laboratory, cosmic ray interacting with the concrete structure, etc.
    (b) The formation of the sonoluminescent bubbles is triggered by 14MeV neutrons from a pulse neutron generator (PNG). The neutron detector will see a large number of events during these neutron pulses. This forms a highly time dependent source of background.
2. The PM tube used to detect the SL signals
    (a) The true SL signals, assumed to be concentrated over a period of a few microseconds around the time of bubble collapse.
    (b) Any random background due to stray light entering the detector at all times, or other electronic noise.
    (c) A background due to interactions of the neutrons (and gammas) from the PNG and the liquid, Pyrex and the PM tube components.

Random events can be due to chance coincidences between any background listed and item 1 and item 2. Table 2 lists the different possible combinations and their associated time structure.

4 Characterizing neutron spectrum background

The setup used to record the background seen by the neutron detector is shown in Fig. 3. The n$-\gamma$ timing, the pulse height, and the time delay between the trigger pulse for the 14 MeV neutron generator and the detected event were all recorded. Because of the high count rates during the neutron generator pulses, the detector was moved farther away from the PNG

Coincident Event	Associated Time Structure
1a - 2a	Cavitation time structure (SL times)
1a - 2b	No time structure
1a - 2c	PNG time structure
1b - 2b	PNG time structure
1b - 2c	PNG time structure

Table 2: **List of possible coincidences in SL-n/γ experiment.**

than normal, to about 150cm. Although the absolute count rate is thereby reduced, the time structure of the detected events can still be measured.

Initialy we used this setup with a 15 μ s trigger pulse operated at 20kHz. The first run was made with the PNG itself disabled, so the detected events represented the room background alone (i.e. source #1 from the previous section). Fig. 4 shows the data obtained over a period of about 10 minutes. On the left the pulse height is displayed, on the right the n-γ discrimination timing pulse distribution. The top two plots show those events identified as neutrons, the next two those identified as gammas, and the lowest plots show the total of all events. Less than 10% of the events are classified as neutrons, presumably from the Pu-Be source which was stored nearby. The total count rate is 100c/s.

Fig. 5 shows the time structure of the same data set. The plots on the left show the time delay between the trigger pulse of the (disabled) PNG and background. The system was set up so that t=o is approximately in the middle of the range. The time calibration is about 13 ns/channel. As expected there is no correlation between the PNG signal and the background.

For the second run the PNG was enabled. Fig. 6 and Fig. 7 show the data collected in this mode. The time structure seen (Fig. 6) shows clearly that the neutron pulse width is about 1.5μs (fwhm), and that about 75% of the events are classified as neutrons. The n*gamma* discrimination is still excellent, confirming that the instantaneous count rate is not too high. The pulse height spectra (Fig. 7) show clearly the edge corresponding to the full energy proton recoils from 14 MeV neutron scattering in the scintillator.

A third run was made with the PNG triggered at 200Hz, still using a 15μs wide trigger pulse. The time structure appears to be significantly different, as shown in Fig. 8. Now the PNG pulse is about 12μs wide. Again we see that 75% of the events are classified as neutrons.

5 Background and time structure seen by the light detector

This has not been measured yet but it is an important variable that will be measured. These data are shown later in this report where the singles data were measured at the same time the coincidence experiment was conducted.

6 First (preliminary) experiment

6.1 The experimental setup and a first look

The setup used in the experiment is shown in Fig. 9. The level adapter was brought over on 6/21 and ran OK. We found out however that the unit was not functioning when we got ready for the run. Not having a spare around we decided to run for a while with Deuterated Acetone and with the neutron generator and cavitation on. Bear in mind, though, that the blocking circuit (shaded components in Fig. 9), was not functional. We counted SL-nγ coincidence for about 20 minutes. The time and energy distribution for the events is shown in Fig. 10. The right column shows pulse height distributions of the n/γ detector signals recorded in SL-nγ coincidence mode, and the left column shows the time distribution of SL-nγ coincidences. As before the bottom row shows undifferentiated signals the second row shows what we identify as γ rays and the top row shows the data for pulses identified as neutrons.

As one can see from the spectra there is nothing to indicate any clustering in time of the SL-nγ coincident events. In the absence of any identifying marker to distinguish these coincidences from random events, one of two courses had to be taken.

- run the coincidence over a larger range of allowed overlap time and than look at the time structure again.
- run two sets of data one with cavitation and one without cavitation and compare rates.

6.2 Second data set - with and without blocking

It would have taken some additional time and effort to change the electronics to allow for longer coincidence time interval so it was decided that we concentrate on repairing the neutron generator blocking circuitry and repeat the 6/22 run with and without cavitation and with and without neutron-generator blocking signal. The electronics was reset and fixed on 6/23 and on 6/25 another set of runs was performed. Some effort was made to have the threshold for light detection in the electronic coincidence circuit match the threshold set by the storage scope trigger level. This we did by adjusting the discriminator level in our SL line so that the frequency of light signals observed at the storage scope matches the frequency of logic signal outputs from the discriminator.

Fig. 11 and Fig. 12 show the n/γ pulse height spectrum from the two runs with and without the mechanical oscillator on. As in Fig. 10 the left column shows SL-n/γ time distribution and the left column presents the pulse height information for the n/γ detector. The second and third row represent γ gated and neutron gated signals, respectively. Again no significant markers are present in the neutron or gamma signals. The rates in the two experiments show some difference and these are listed in Table 3.

	no cavitation		with cavitation	
	counts	rate	counts	rate
Elapse time	902s		1126s	
nγ singles	711654	789 c/s	867445	770 c/s
SL flashes singles	155	0.17 c/s	1279	1.14 c/s
Coincident Events	41	0.045 evts/s	71	0.063 evts/s
Coincident neutrons	10	0.01 n/s	12	0.01 n/s
Coincident γs	4	0.004γ/s	9	0.008γ/s

Table 3: **Summary of events.**

The spectrum was too sparse to show aggregates that can be attributed to γs or neutrons. A background spectrum based on random coincidences set up with the n/γ detector and a 12kHz pulser (substituting for the SL pulse) provided enough counts to determine the neutron and γ gate regions to be used in the actual SL- n/γ coincidence experiments.

The last run performed on 6/25 was with cavitation on but with a signal that blocks the n/γ detectors for 15μsec starting at the time the neutron generator was turned on (shaded part of circuit in Fig. 9). This experiment was run for 20 minutes and showed very few coincidence counts (6 total at a rate of 0.003 events per second) with two identified as neutrons.

6.3 Analysis and interpretation of results

It appears that blocking the "penetrating radiation" signals during the time of the Neutron generator burst has a large effect on our coincidence rate (more then one order of magnitude reduction in rate). Because of the high rate of neutrons and γ during the time the neutron generator is active, about 2.6×10^5 counts per second, the likelihood of random coincidences between the light signal flashes and the n/γ signals is increased.

The short duty cycle and the large average rate indicate that the rate of neutron reaching the detectors is quite large. The average n/γ singles rate was about 800cts/sec. This increment in count rate is an average acquired in 200 bursts/sec each 15μsec long - i.e an effective duty factor of 0.003. The derived instantenous rate is close to 800/0.003 counts/sec i.e 2.67×10^5 c/s.

The rate of light signals, without cavitation on is 0.17counts/sec. The random rate over a 2μsec period is expected to be:
$2\times10^{-6} * (2.67\times10^5) * 0.17 = 0.09$ events/s. This rate is in line with the observed rate.

If we block the Generator signal we have only the background rate of 100c/s to contend with - and therefore a much smaller, predicted random rate. Such a decrease in the random rate may enhance our chances to notice any significant additional neutron source if it exists.

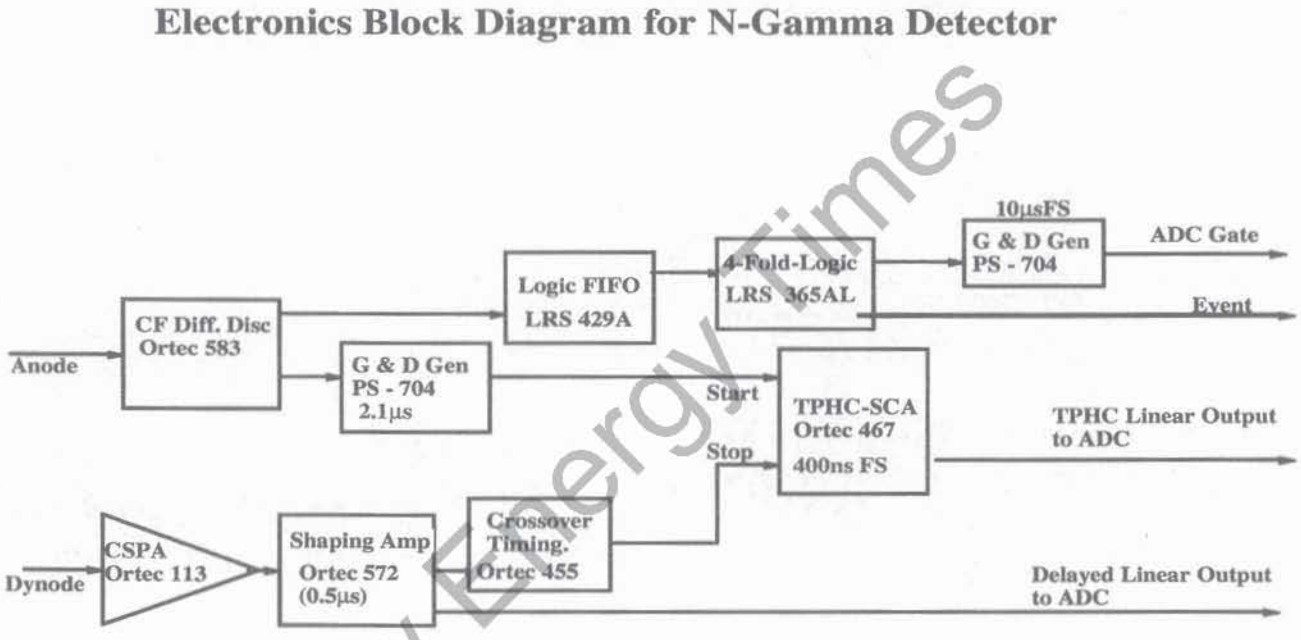

Figure 1: Block diagrams of the n-γ discrimination setup used with the neutron detector

Figure 2: The vertical dimension is the neutron-γ separation coordinate - the larger values are neutrons.

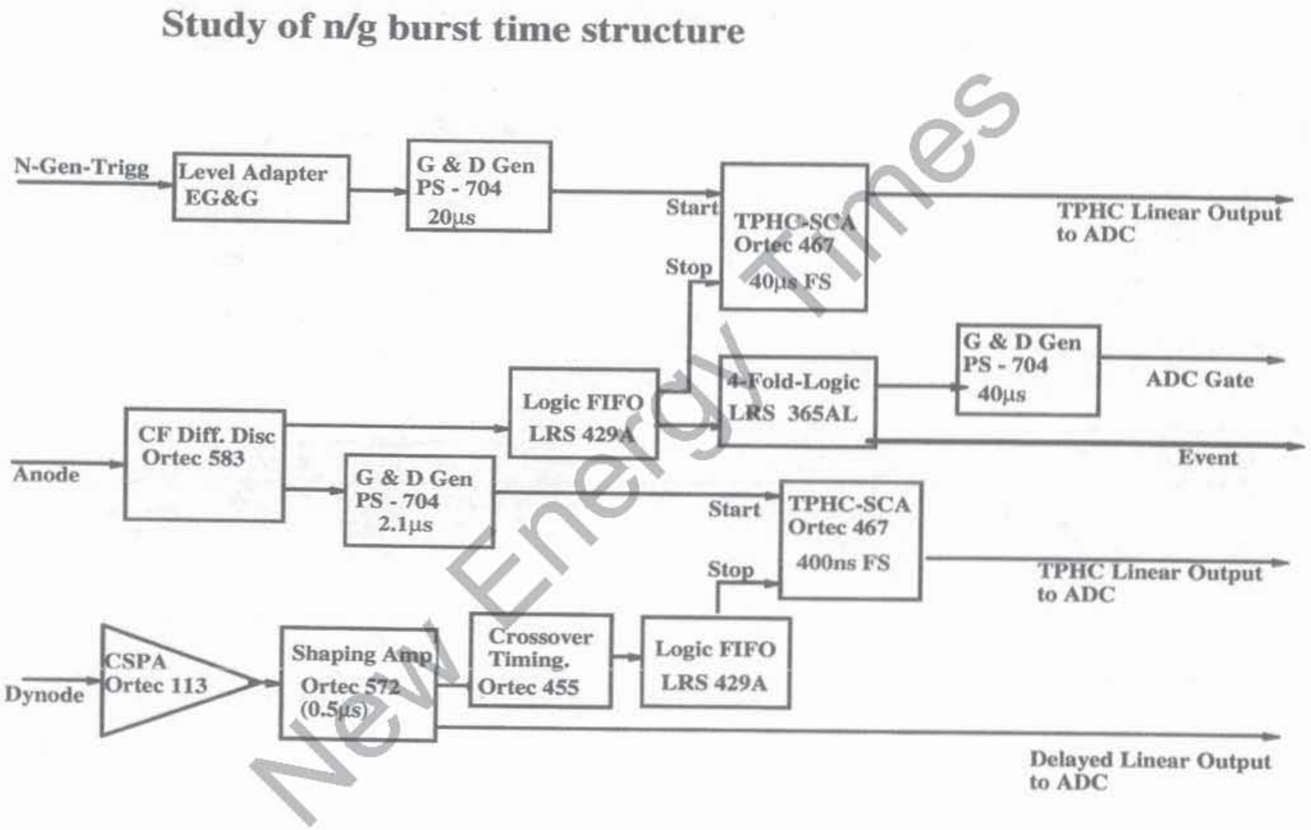

Figure 3: Block diagrams of the setup used to study the neutron background

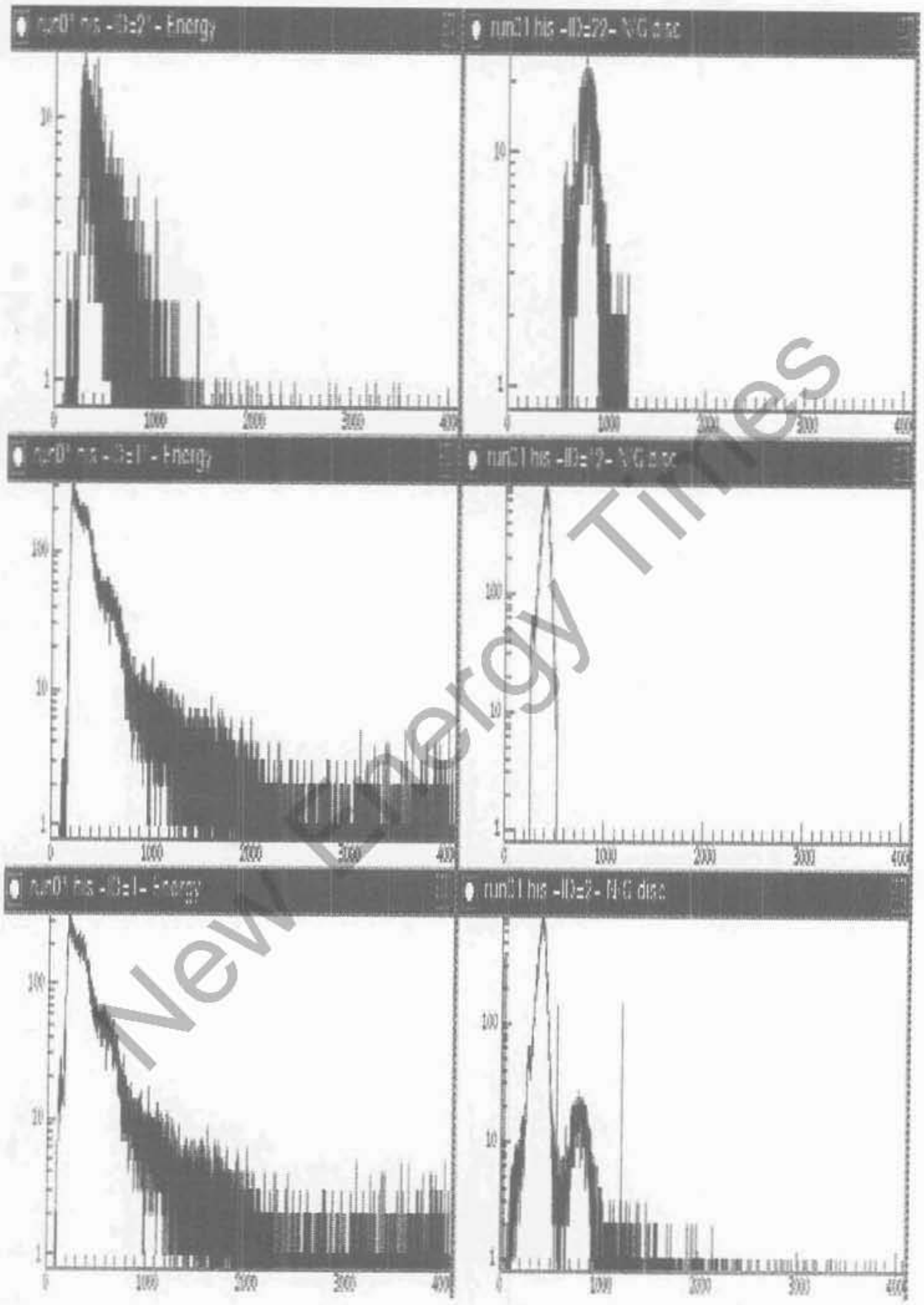

Figure 4: Histograms showing the pulse height spectrum of background radiation present with neutron generator pulse as reference but with the generator not running.

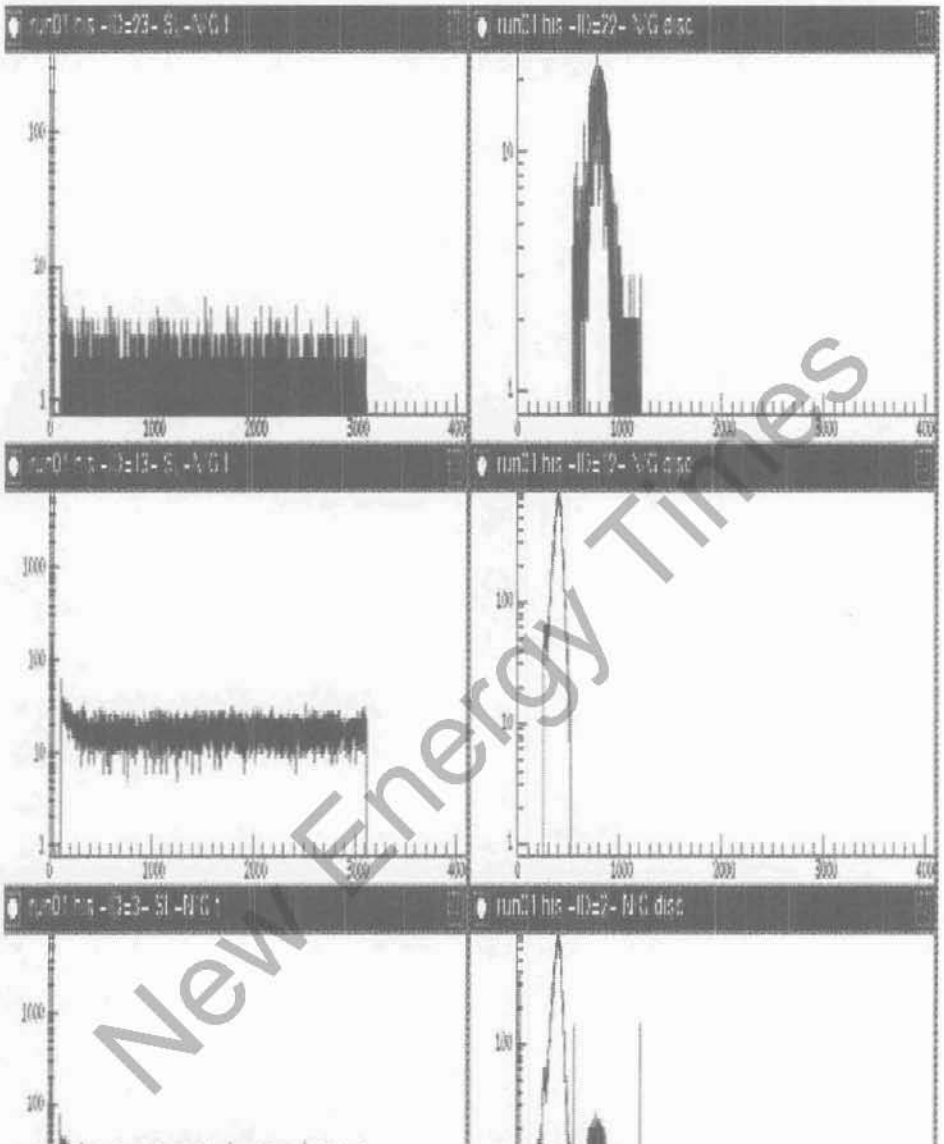

Figure 5: Histograms showing the elapsed time spectra of background radiation present with neutron generator pulse as reference but with the generator not running.

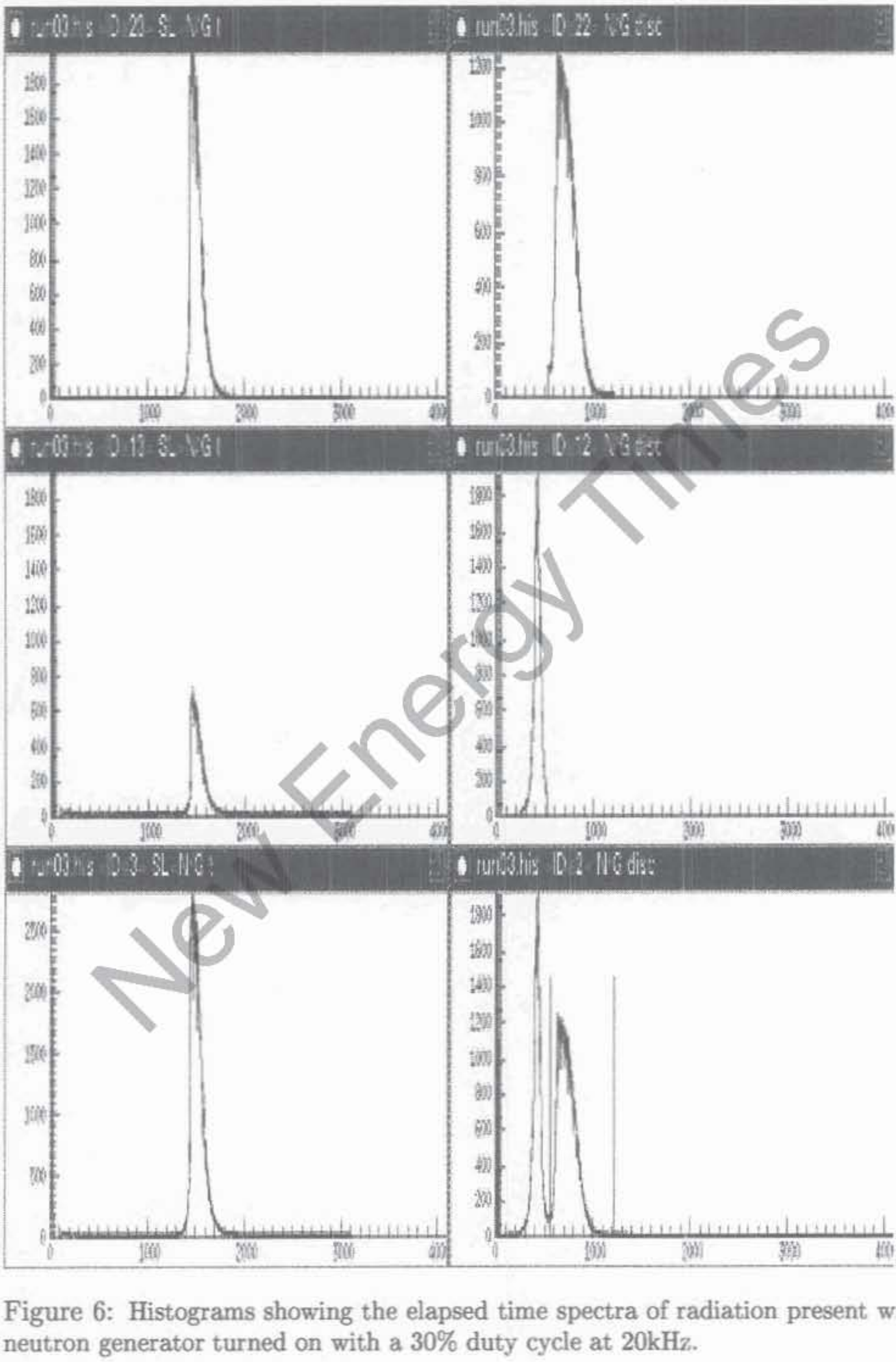

Figure 6: Histograms showing the elapsed time spectra of radiation present with neutron generator turned on with a 30% duty cycle at 20kHz.

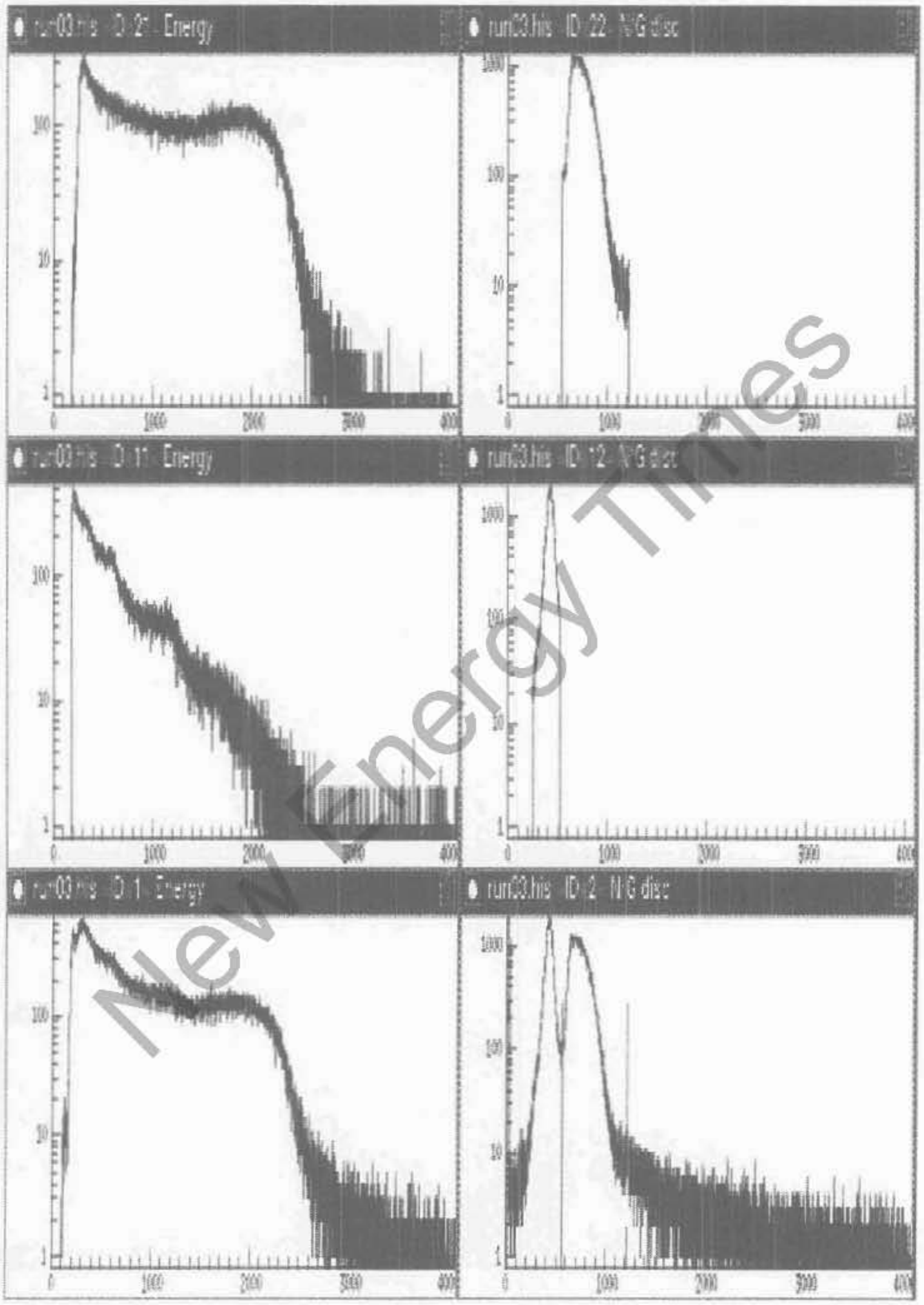

Figure 7: Histograms showing the pulse height spectra of radiation present with neutron generator turned on with a 30% duty cycle at 20kHz.

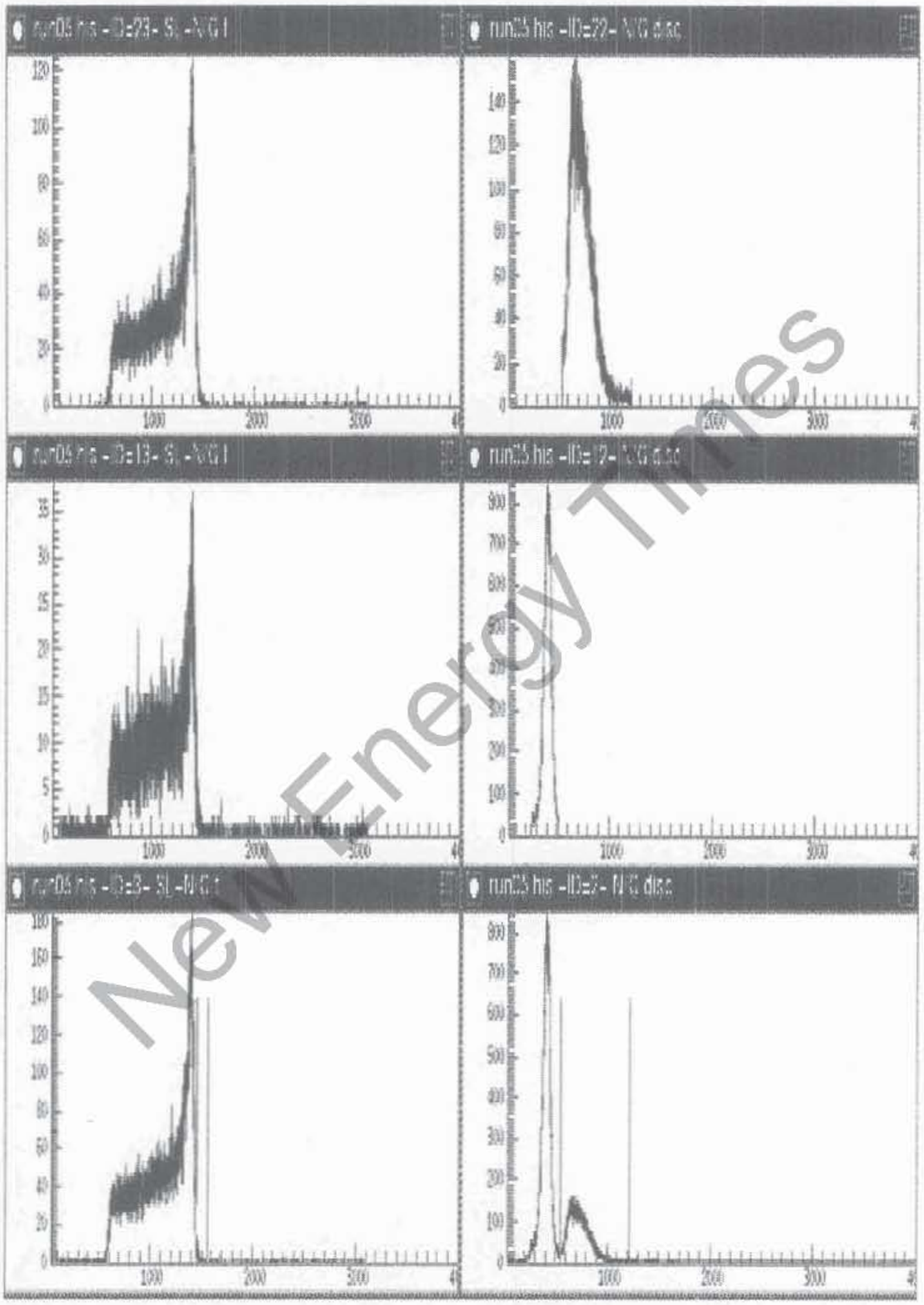

Figure 8: Histograms showing the elapsed time spectra of radiation present with neutron generator turned on with a 0.15% duty cycle at 200Hz.

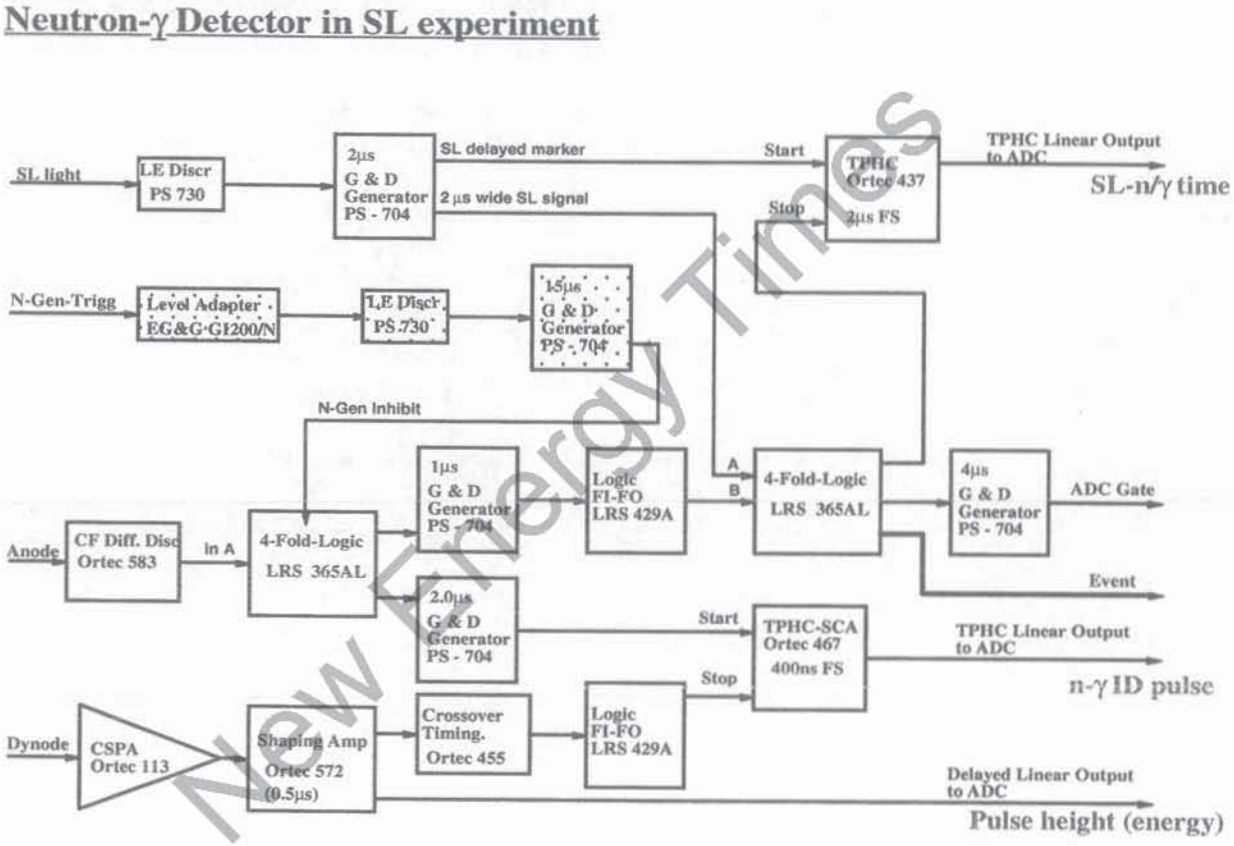

Figure 9: Block diagrams of the setup to study the neutron SL-nγ coincidence events

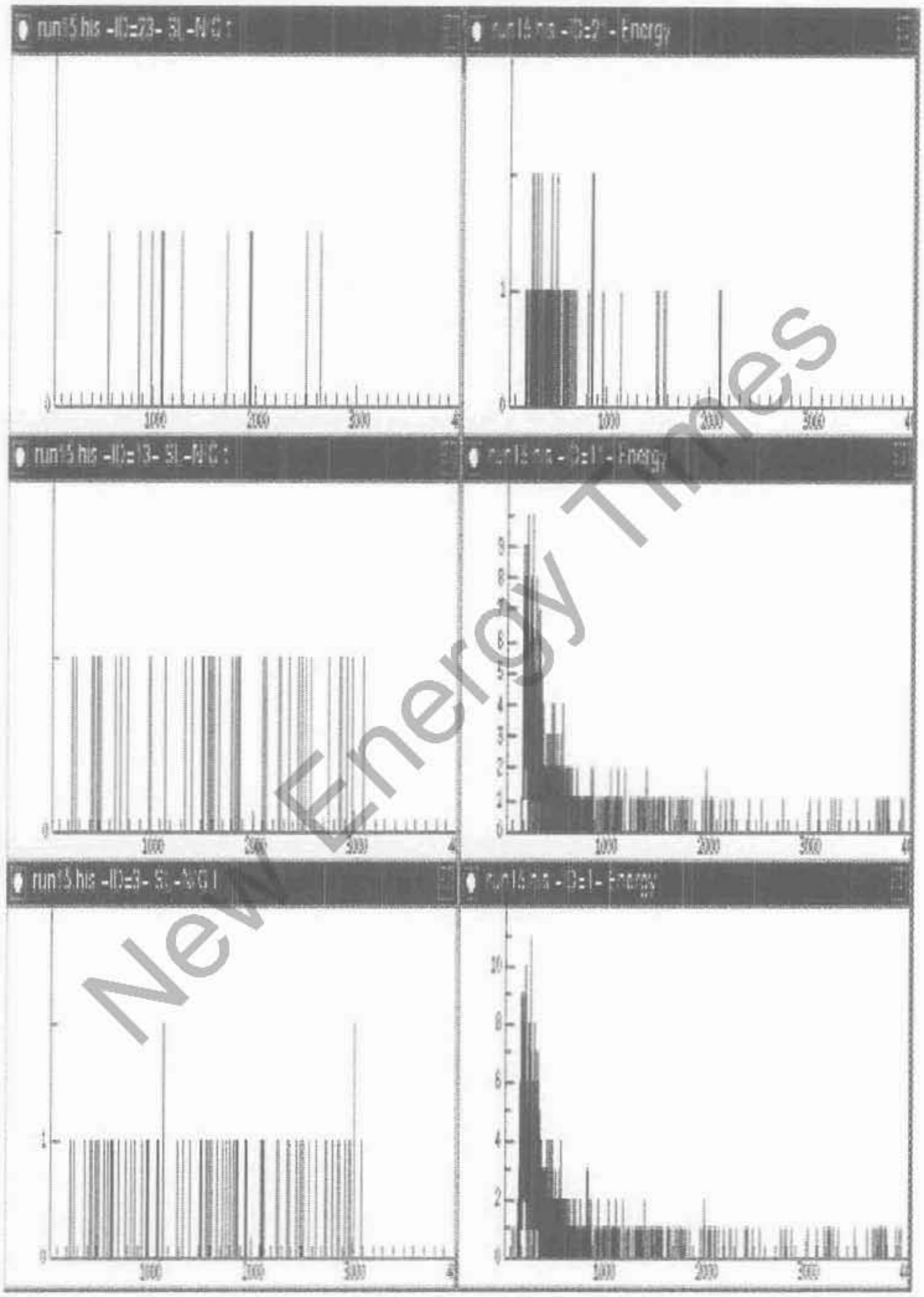

Figure 10: Histograms showing the pulse height distribution of pulses for the n/γ and the time distribution within the 2μsec bin, of the SL-nγ coincidences.