Fax nos. Dan 574-1268
Rui 570-0940

Evaluation of discrepancy between coincidence measurements performed by PD and ETD

D. Shapira[1]
[1]Physics Division Oak Ridge National Lab. Oak Ridge, TN.

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1 Background

There were two measurements performed looking at coincidences between light signals from the cavitating fluid and nuclear radiation (neutrons and gammas). The paper had only partial information about the relevant dimensions. Follow up discussions and correspondence shed some additional light on dimensions used. Using all the information garnered from conversations and correspondence I came up with a tentative two dimensional drawing showing essential components of the experimental setup. I believe that a figure similar to Fig. 1 where an attempt is done to put forth all the relevant information will be very helpful to readers of the paper. One can add other information too but dimensions are very important, one should also mention the parafine wall erected near by as well as the fact that the PD detector and the flask with acetone were perched on wooden blocks (did not draw these in!).

Using the numbers from Fig. 1 one can calculate the solid angle ratio for the two detectors. We determined the 'viewing efficiency' of a detector's surface by using the distance along a line of sight connecting the source (FLASK or PNG) to the largest cross sectional area of the detector which is perpendicular to this line of sight.

As shown, the area visible from the center of the flask is the cylindrical front area of the detector at a distance of 7cm. A tilt will diminish this area a little but will expose some of the side panel positioned at a larger average distance.

The different detector's areas involved are:
On ETD detector:
Front cylinder = 20 cm^2

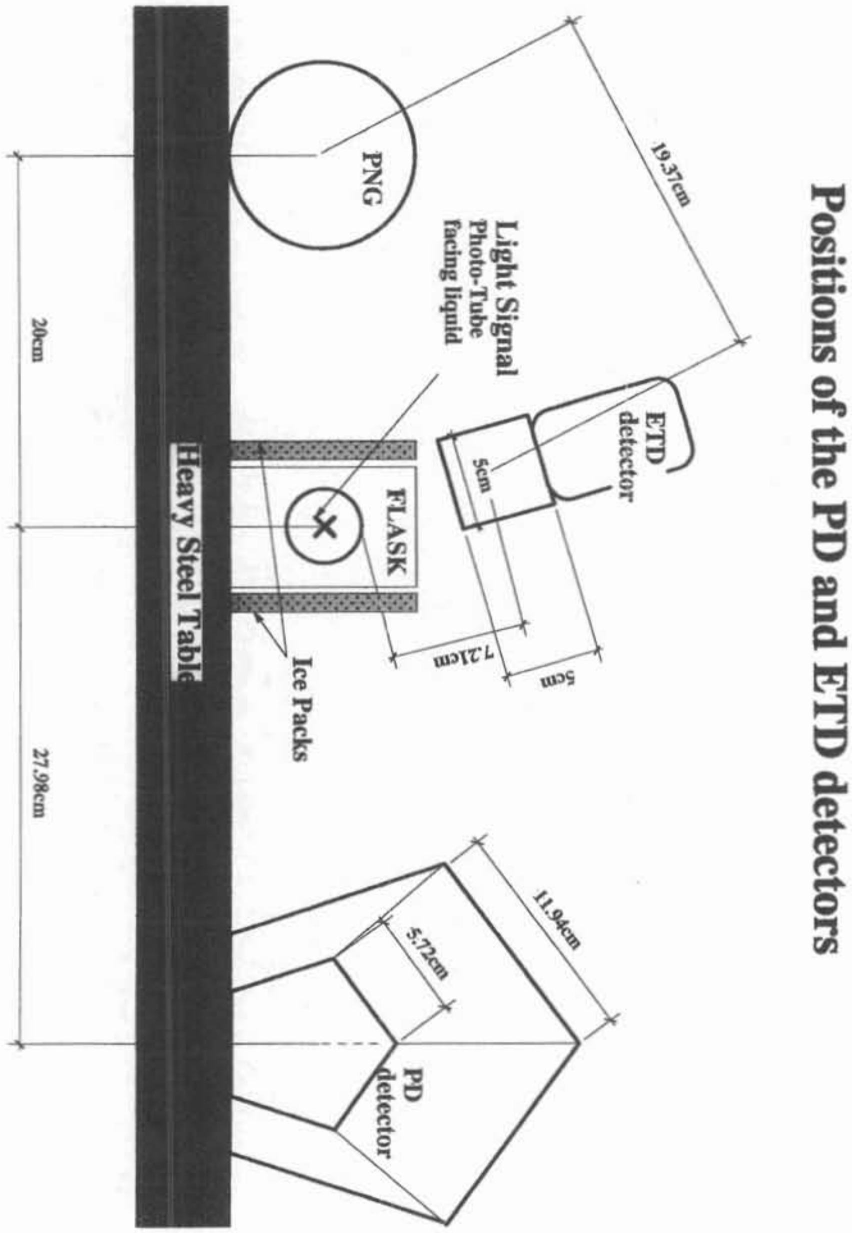

Figure 1: Layout of the experimental setup used in the two experiments to look at nuclear radiation emissions. The scintillator in the detector labeled ETD is cylindrical and the PD detector has a scintillator volume bound by two pentagons shown and a side length of 21 cm

Largest side view (perpendicular) = 25.8 cm^2
On PD detector:
Largest side view (perpendicular to line of sight) = 283.2 cm^2

Table 1 below lists in some detail the different contributions to the solid angle $\Omega = \frac{Area}{4\pi \times Distance^2}$ for the different detectors. My calculations assume a tilt of 30 degrees for the ETD detector. The tilt is off the perpendicular line connecting the front of the ETD scintillator to the center of the flask, (the frontal area is reduced by cos(30) and the portion viewable from the side is scaled by sin(30))

Detector	Source	Viewable Area		Average Distance		Solid Angle
		1^{st} plane	2^{nd} plane	1^{st} plane	2^{nd} plane	
ETD	FLASK	17.55	12.9	7.2	9.7	0.0375
PD	FLASK	283.2		28.		0.0287
ETD	PNG		25.80		20.	0.00513
PD	PNG	283.2		48.		0.00978

Table 1: Solid angles calculated assuming a 30 degree tilt of the ETD detector with respect to the line connecting the center of the FLASK and the center of the front plane.

The experiment with the large PD detectors was done only with deuterated acetone. Both experiments are discussed in detail. The experiment with the ETD detector is described in a paper submitted to Science and the PD experiment is discussed in a report written to lab management in July 2001.

2 Comparisons of results from the two experiments

Table 2 summarizes the results from the two sets of experiments.

Both experiments agree as far as the existence of enhancement in the singles data is concerned. The enhancement seen in the singles n-γ counts when cavitation is turned on is observed in both experiment. There is a quantitative difference, though. The excess counts observed with the PD detector were about 10^4 counts over 3800 seconds (a 4% effect). I.e $10^4/(3800*200) =$ 0.013 n-or-γ observed per PNG pulse. This corresponds, approximately, to 33 neutrons or γs emitted per PNG pulse, or 6600/sec. This number is about an order of magnitude less then the 5-8*10^4/sec quoted for the experiments with the ETD detectors (page 8 in submitted paper). The PD detector's

in what regime

Observation	Time Frame	ETD detector	PD detector
Single n-γ	Undetermined	Positive	?
Single n-γ	During PNG pulse	?	?
Single n-γ	During PNG off time	?	Positive
Coin. SL and n-γ	Undetermined	Positive	?
Coin. SL and n-γ	During PNG pulse	?	?
Coin. SL and n-γ	During PNG off time	?	Negative
Single neutrons	Undetermined	Positive	?
Single neutrons	During PNG pulse	?	?
Single neutrons	During PNG off time	?	?
Single neutrons	500-5000μs after PNG	?	Negative

Table 2: Summary of results from different experiments - Positive means enhancement with cavitation was found, Negative means enhancement with cavitation was not found, and ? means no data available.

efficiency for neutron detection was measured using a PuBe source emitting $2*10^6$n/s placed 30cm away from the detector. The measured neutron yield of 800 n/s corresponds to an efficiency of $4*10^{-4}$ at 30 cm.

With regard to the coincidence data, the two measurements completely disagree. In the PD experiment we DO SEE an increase in the coincidence rate when we turn on cavitation. A careful examination of the time distribution of coincidence, n-gamma singles and light signals during the time duration between PNG pulses was carried out in the same experiment. The data show that the coincidences seen when cavitation is turned on are due to random coincidences between light signals and nuclear radiation (n-γ). With cavitation turned off the coincidence rate decreases dramatically but also the expected random rate is near zero because there are almost no light signals detected after the PNG pulse subsides. The distribution of measured time intervals between light detection and n-γ detection does not show any significant clustering around zero time difference. Such clustering is anticipated if these coincidence were due to nuclear radiation emitted from the imploding bubbles.

The discrepancy for the coincidence results must be understood. One could propose different reasons why the enhancement in SL-light and n-γ coincidence rates is seen in experiments with the ETD detector but does not appear in the experiment done with the PD detector. The following questions have been raised:

- Is the PD detector's efficiency for 2.5 MeV neutrons coming from the acetone container lower then corresponding ETD detector's efficiency?

- Could the larger size of the PD detectors result in a much larger γ efficiency, thus increasing the gamma background producing randoms that bury the signal?
- Are the extra Neutron - Light signal coincidences observed in the ETD experiment generated during the PNG burst time, (events intentionally blocked out in the PD experiment)?

2.1 Discussion and qualitative arguments

2.1.1 Relative efficiencies to neutrons and gammas

A question was raised about the relative efficiency to neutrons and gammas being very different in the PD and ETD detectors. The volume of both detectors is large enough to produce a large signal from recoiling electrons as well as protons. What are referred to as "thin" neutron scintillators (used to suppress signals from γ rays) are few mm thick (at least in one dimension) [1]. There may be a difference in the ratio of photon/neutron yield observed with both detectors but it is not too significant. Fig. 2 shows a Pulse Shape Discrimination spectrum obtained with our detector when it was placed 150cm away from the PNG. At this distance it was possible to operate the detector also during the PNG pulse duration and obtain decent n-γ separation for all hits. The ratio of Gammas to Neutrons in this spectrum is about 4.4:1. Considering the large (150 cm) distance from source to detector it appears reasonable. There are no data in the paper regarding this ratio but I recall from conversations that it was not very different. Fig. 3 shows the PSD separation for a short run with a Pu-Be source placed about 30cm away from the detector surface. Here the ratio is close to 1:1!

2.1.2 Neutron energy thresholds in PD and ETD detectors

Another question raised by Prof. Block was the difference in the neutron threshold in the two experiment. We did not check our threshold using ^{60}Co γ rays but a comparison of our neutron spectra with the one presented in figure 3.4(b) of the manuscript submitted to science shows that the PD detector had a larger dynamic range (measured as the ratio of channel numbers near the 14MeV shoulder and the threshold channel number). Figure 4 shows a neutron spectrum obtained when we moved the PD detector to a distance 150cm away from the PNG. At this distance count rate was low, no

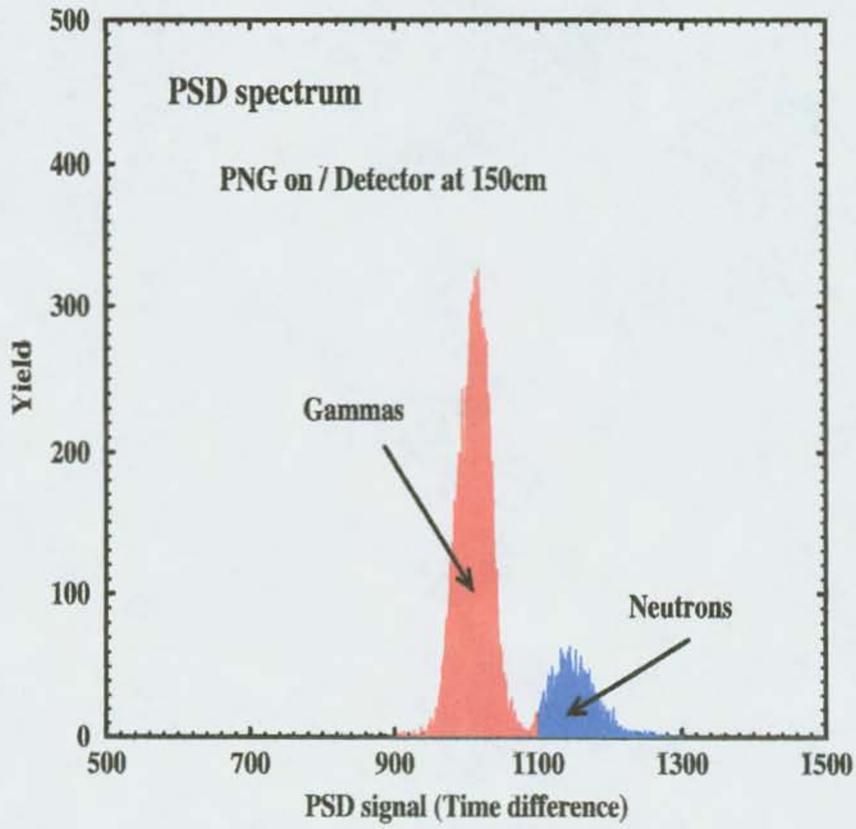

Figure 2: A pulse shape discrimination spectrum. This is a time spectrum showing the difference between a pulse start time and the cross over after differentiation

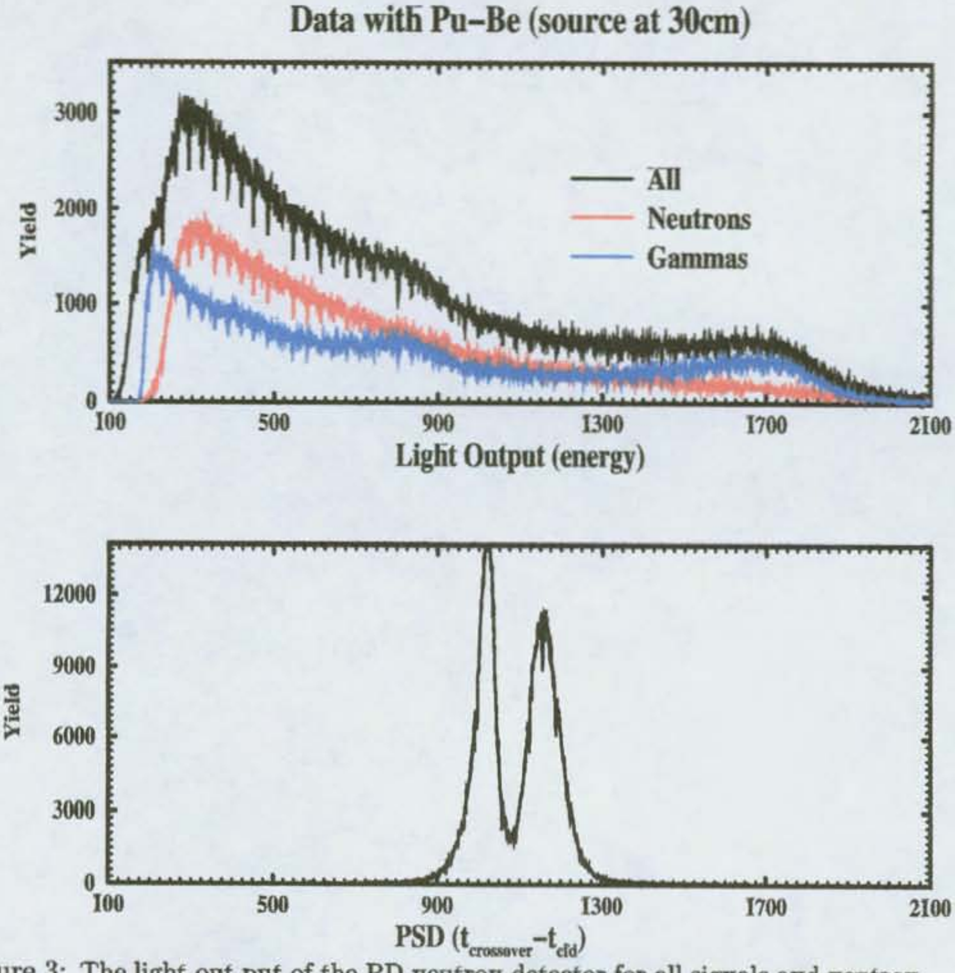

Figure 3: The light out put of the PD neutron detector for all signals and neutron and γ gated signals. The PSD pulse is shown in the lower part.

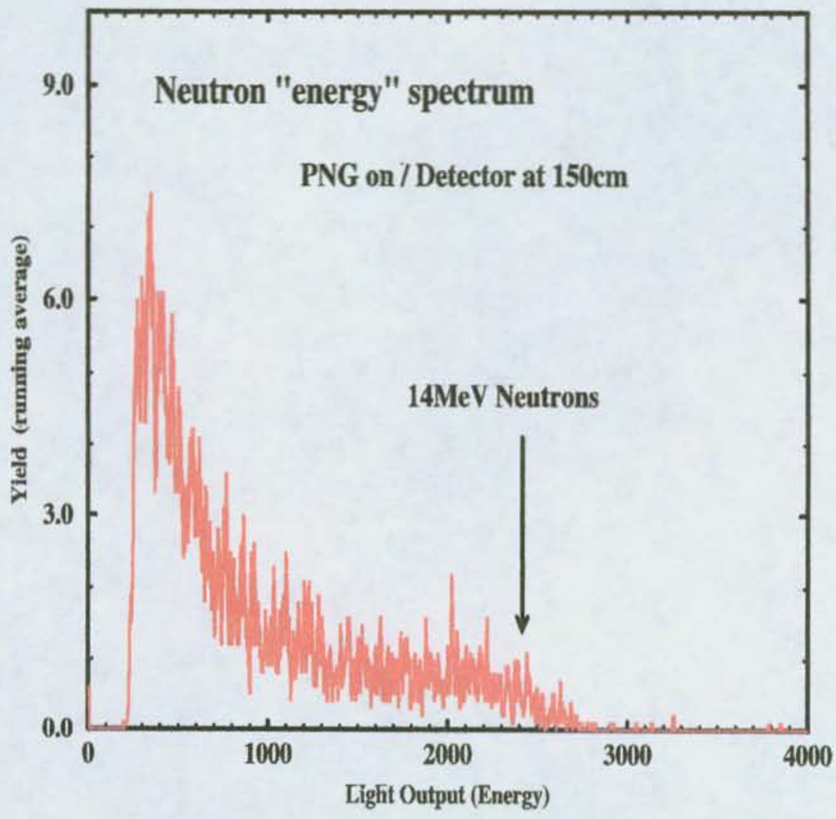

Figure 4: The light output of the PD neutron detector for signals gated on neutrons in the PSD pulse.

signals were blocked and n-γ discrimination was possible for all signals. The apparent dynamic range here is better than 1:10. This should be sufficient to trigger on some of the 2.5MeV neutron signals and definitely better then the 1:5 ratio apparent in figure 3.4(b) in the submitted article. Thus the PD detector would have been more sensitive to 2.5MeV neutrons than the ETD detector. Fig. 3 also shows the combined and the separated neutron and γ spectra acquired with a PuBe source placed about 30 cm away from the PD detector. (Note that the γ spectrum peaks around 1700 which is close to where the PuBe neutron spectrum tapers off at around 8-9MeV). One should also note that in the PD experiment the event trigger was determined by the leading edge (CFTD) discrimination and since we did not attempt n-γ discrimination in the coincidence measurement the threshold for coincidence or n-γ singles events acceptance as determined by the CFTD threshold and the SL discriminator is lower. The higher threshold setting used for the cross over discriminator is used only for PSD n/γ separation. Since the data is taken event by event this higher threshold sets in only when we attempt to separate neutrons and γ. This effect can be seen at the low energy end of the spectra shown in Fig. 3.

From the discussion above, it should be apparent that I find it hard to accept lower neutron threshold or high photon yield are as root causes for the discrepancy seen in the two coincidence experiment.

2.2 Quantitative studies

We are left therefore with the third possibility - that the coincidences seen in the experiment with the ETD detector occur mostly during the PNG burst duration. The following sections present some quantitative arguments addressing the following questions.

1. Given the relative efficiency of the PD and ETD detector would the PD detector be sensitive to the effect seen in the ETD experiment?
2. Given the relative efficiency of the PD and ETD detectors what would be the signal seen by the PD detector if pulses from the PNG burst were not blocked?

2.3 A first "what if" scenario

It has been suggested by Dr. West that we perform the following analysis.

I. Take the difference (signal) seen in the experiments done with the ETD detector (The excess counts between -2 to +2 μseconds).

2. Scale these counts to account for the difference in run time between the experiment with the ETD to the time period we ran with the PD detector.

3. Scale the number of counts to account for the difference in solid angle ratio between the ETD and PD detectors.

4. Superpose the "scaled" counts in the appropriate time bins (-2,+2) on to the coincidence spectrum obtained in the experiment with the PD detector.

The argument goes that if these counts do show up as a signal in our spectrum then we would have seen the effect if it were there during the experiment. This argument holds true if the signal that was seen without time blockage was present with all its strength at the later time and if the experiment with the PD detector did not suffer from higher threshold for neutron detection.

The excess counts in the region between -2 and +2 μs, as averaged from the 6 runs I received data on, is 34.5 counts. The average time span for these runs is 1020 seconds (page 9 in article). The solid angle (see table. 1) is 0.00375.

The runs with the PD lasted about 3850 seconds and the solid angle for this detector is 0.0287.

The corresponding "scaled up counts" are:
99.6=[34.5*(0.0287/0.0375)*(3850/1020)].

Fig. 5 shows the coincidence spectrum from the run with the PD detector with 40 counts added to the two time bins near zero. The effect is a noticeable signal, which would have been clearly seen if it had occurred.

2.4 comparison of detector rates

In written comments on Dec 19, 2001 Prof. block calculated the rate of neutrons and gammas hitting the detector during the PNG pulse duration. I find one serious problem with his calculation. He assumed that the PNG is pulsed 20000 times a second (his equation 2 in the text). Actually this was the pulse rate used for the cavitation. In most of the experiments that I witnessed, the rate of PNG pulsing was about 200/sec. Therefore if I take Prof. Block's estimate of 0.5 neutron + 0.5 γ hitting the detector during a PNG pulse (i.e 1 count per pulse), a number based on assuming a 20000 rep rate for the PNG, and scale it to a 200/s rep rate, the number of hits on the detector during one PNG pulse period becomes 200!

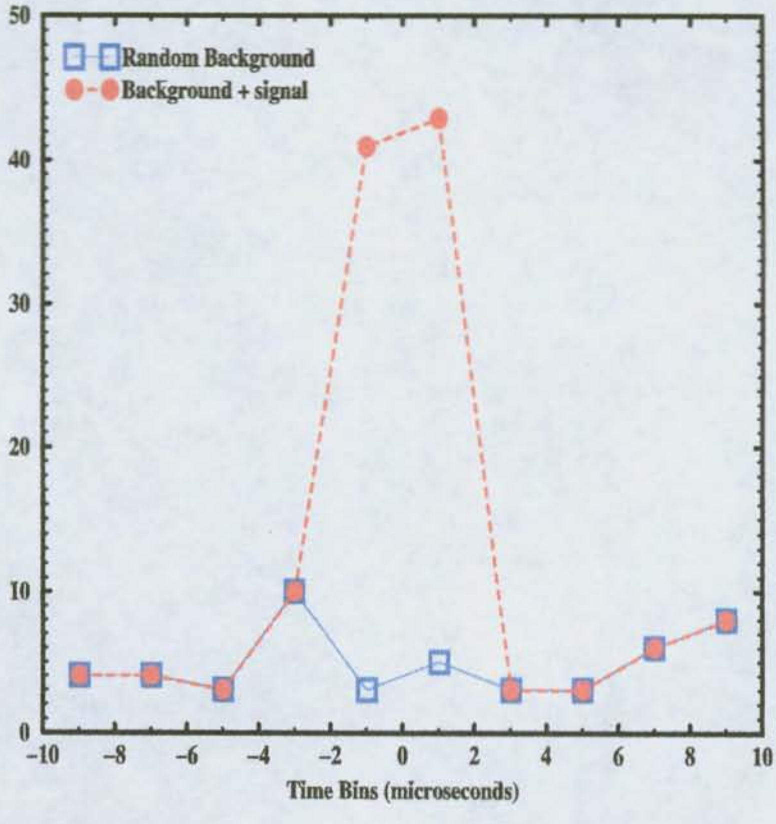

Figure 5: The coincidence spectrum acquired with the PD with superposed "scaled up counts" corresponding to the effect seen (for all times) with the ETD detector.

2.4.1 A second"what if" scenario

In a similar fashion in which we estimated the impact of coincidence data seen by the ETD detector on the PD detector if they were there during time periods outside the PNG pulse duration. One can also "reverse" the argument and try and see the impact of the light pulses (seen during the PNG burst time in the PD experiment) on the overall coincidence rate in the ETD experiment had we eliminated the blocking of n-γ signals during the PNG burst.

1. Take the (normalized) difference in light signal detected during the PNG burst period for runs with and without cavitation.

2. Estimate the number of random coincidence - within a 20μsec interval that would arise with the emission of N neutrons per pulse.

The numbers and rates of light signals measured in the PD experiments appear in Table 3.

Experiment	Raw counts	Rate	Inst Rate	Per 20μs pulse
With Cavit.	408	0.106/s	265/s	1.325
No Cavit.	350	0.099/s	248/s	1.24

Table 3: Table showing SL detector counts and derived counting rates average and instantenous.

For an average of 1 neutron per pulse a random coincidence rate of about 50% of the number of SL signals that occur during this same time period is expected. This number (0.5/s) is about half the coincidences counted in 15 minutes (about 100) in the ETD experiment. One should bear in mind that there may be more than one neutron detected during this 20 μsec. period. A rough estimate yielded something close to 100/sec. In that case random coincidence are almost a certainty any time a light pulse occurs (during that time period). Using efficiency ratios from table 1 we would expect that the ETD detector see some 183 random coincidences without cavitation and 214+51 with cavitation (if PNG is the source). I conclude, therefore, that the expected random rates are very close to the rate of SL-nγ coincidences observed in the ETD experiment. Furthermore because of the relatively narrow time structure of SL and the PNG pulse, the overall coincidence spectrum will exhibit a time structure of the PNG pulse, a few μseconds wide.

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3 Conclusion and recommendation

At present I do not find any reason to discard the results of the coincidence experiment done with the PD detector. I can not see any reason why we should not have seen the same coincidences seen with the ETD detector. This leaves only the last explanation for the discrepancy - the coincidences that they see in the ETD experiment OCCUR DURING THE TIME THAT THE NEUTRON GENERATOR FIRES.

In order to make more accurate quantitative comparison of the experiment it is incumbent on us to get a good measure of the relevant singles rates (both light and n-γ), and the coincidence rate and their time distributions. With such data one can calculate the probability of a random coincidences occurring during, before and after the PNG pulse duration. Further experiments that will look at coincidences during, before and after the PNG pulse duration can better establish the true connection, between the light signals and the excess of nuclear radiation. An important component of such experiment would be to continuously monitor the production rate of neutrons by the PNG. There may be some difference in the trigger pulse from the circuit that fires the PNG when the cable to the piezo-electric oscillator is disconnected. This may results in a different trigger pattern when cavitation is on or off.

Barring the possibility of additional experiments I think the paper has to account explicitly for the findings of the PD coincidence run and acknowledge that it puts in question the interpretation of bubble collapse as a source of nuclear radiation. I also believe that the SL regular "beat" occurring between 500 and 2000 μsec following the PNG pulse is very interesting and should be highlighted.

References

[1] J. A. Harvey and N. W. Hill "Scintillation Detectors for Neutron Physics Research", NIM 162 (1979), 507. (special issue on nuclear detectors.)