Observation of High Multiplicity Neutron Emission Events from Deuterated Pd and Ti Samples at BARC: A Review

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1. Objective and Methodology: In lenr devices, are neutrons generated one at a time in a random fashion following Poisson statistics or in bursts of 2, 5, 10 or even more neutrons as in a spontaneous fission neutron source? The multiplicity distribution of neutron emission can throw much light on the mechanism responsible for neutron generation – could some neutrons be emitted during a type of chain nuclear event for example?

The statistical time spread (typically 25 µs) that occurs during the slowing down process when a bunch of simultaneously produced fast neutrons impinges on a large hydrogenous moderator assembly is exploited for detecting these neutrons separately in a time resolved manner. Thermal neutron detectors such as BF_3 or He^3 gas proportional counters embedded in the moderator block can register these neutrons individually and sequentially.

2. Statistical Analysis Techniques: Two different techniques were used to determine the statistical characteristics of the pulse train issuing from the BF_3 or He^3 neutron counter banks (Srinivasan et al., 1990). In the first method the frequency distribution of counts in 20 ms time bins was recorded. In each sweep of the pulse train there were 1000 such bins, with a 280 ms separation between the

20 ms bins (as required by the data acquisition system), consuming in all a real time duration of 5 minutes per 1000 bin sweep. (The duration of the counting interval selected, namely ~20 ms, was a compromise between the total volume of data required to be stored and the resolution time of the study.)

The second approach to measuring the statistical characteristics of the pulse train was an adaptation of the "artificial dead time" method developed originally for investigating neutron density fluctuations (Srinivasan, 1967; Uhrig, 1970) in experimental fission reactors as well as for the passive neutron assay of plutonium in the safeguards field (Degweker, 1989; Ensslin et al., 1978; Jacquesson, 1963). When more than one neutron from a neutron burst is registered by the BF_3 or He^3 detectors, the corresponding electronic pulses will all be time correlated and closely spaced within about 100 μs of each other. In such events the second, third and subsequent pulses of the "family of pulses" are diverted by a 100 μs wide "artificial dead time gate" into a separate "burst counts analyzer", while the leading pulses are totalized separately.

Several authors (Degwekar & Srinivasan, 1990; Iyengar et al., 1990; Shyam et al., 1994; Srinivasan et al., 1990) discuss in detail the theoretical aspects of both these statistical techniques in the context of lenr experiments. For a purely random (Poisson) pulse series wherein N_0 is the average count rate and t is the counting bin time interval (in this case 20 ms) and for the case when N_0t is <<1, the probability of registering one count in a single 20 ms interval is N_0t; $[(N_0t)^2]/2!)$ gives the probability of getting doubles, $[(N_0t)^3]/3!)$ that of getting a multiplicity of three counts and so on. Note that the probability of getting higher order multiplicity counts steadily decreases.

If now there are s burst events per sec generating ν neutrons per burst, superimposed on the random background and the neutron detection efficiency is ε, then the contribution of the burst events to the overall count rate would be sνε. The probability of getting r counts in time t from burst events is governed by a binomial distribution. Table I of Sec. 4 in Iyengar et al. (1990) summarizes the expressions for the contribution to the various orders of multiplicity counts from random and burst events. Table II of the same paper gives numerical examples with typical parameters for the expected frequency distribution of counts for random and bunched neutronic events. The main point brought out is that whereas for random events and low count rates, the probability of getting doubles, triples etc. is extremely small, in the case of burst events these probabilities are non-negligible. Interestingly for burst events the peak of the multiplicity distribution actually shifts to higher multiplicity values as the product νε increases. Thus when the product νε exceeds unity (as for example when a bunch of 100 neutrons are emitted in a single event and detection efficiency ε is 10%) the probability of registering three or four counts per interval could be even higher than that of singles or doubles counts!

3. Frequency Spectrum Measurement Runs with Electrolytic Cells (May–June 1989): Several frequency distribution measurement runs were carried out during May–June 1989, both with a Milton Roy type Pd-Ni electrolytic cell and a couple of deuterium gas loaded titanium targets, details of which are presented in Iyengar et al. (1990) and also summarized in Srinivasan (in press). (Table III of Iyengar et al., 1990, gives a summary of these runs.) In these measurements one of the thermal neutron detector banks was used for monitoring the test lenr device while the other, placed at a distance of 1.5 m from the device, served as a background neutron monitor. The efficiency of detection for neutrons emanating from the lenr source was in the range of 0.5% to 1.5%.

The statistical characteristics of background counts were first studied to ensure that the equipment was functioning properly. This was done both in the presence of (overnight run of 26/27 May—cell not switched on) and absence of (2 to 5 June) the Milton Roy cell. During the latter 63 hour background study not even once, out of ~750,000 trials, did either of the detector banks register three or more counts in any 20 ms time bin, confirming that the equipment was functioning very satisfactorily and also that there were no high multiplicity neutron burst events in the background. The average background count rate during this campaign was ~0.023 cps in the BF_3 bank and ~0.43 cps in the He^3 bank and the frequency spectrum of counts recorded corresponded strictly to a Poisson distribution.

In the quiescent Milton Roy cell study conducted earlier (26/27 May), the BF_3 counter bank monitored the electrolytic cell while a plastic scintillator (NE 102A) biased to register only neutrons of energy >9 MeV monitored cosmic ray background events. To our surprise a few very high multiplicity events, even as high as 10 to 15 neutron counts, were registered in some of the 20 ms bins (unlike the background only study discussed above). However there were no high multiplicity counts whenever the plastic scintillator also recorded a very high energy neutron event in coincidence with a BF_3 bank count. This indicated that the source of the high neutron multiplicity events was the quiescent Milton Roy cell and not cosmic rays. The indication that neutrons are often also emitted by a non-operational but preloaded electrolytic cell or stand alone deuterated target has since been observed at BARC on several occasions.

Frequency distribution measurement runs with an operating Milton Roy cell commenced on 12 June. The first neutron emission episode lasting ~5 minutes duration occurred 30 minutes after commencement of electrolysis. Two more such episodes were observed about an hour later. The cell current was then switched off (evening of 14 June) but surprisingly three additional short neutron emission episodes occurred within a few hours of electrolysis being terminated. During these episodes, the neutron count rates were in the range of ~0.5 to 1.7 cps, which corresponded to between 4 to 14 times that of the background value of ~0.12 cps. In four out of the above six episodes, count multiplicities of 2, 3, 4, 5 and even 10 were recorded at least once each. Throughout this period lasting several days the background counter did not register any noticeable increase in count rate; nor were there any multiple counts events.

On the evening of 16 June, an extended 2.5 hour long neutron emission episode took place, in spite of the cell not having been operated for 52 hours prior to that.

The count rate during this wide neutron emission episode attained a value as high as 20 cps at the peak. Even the background neutron monitor which was 1.5 m away indicated a small increase in count rate, commensurate with its efficiency for neutrons emanating from the Milton Roy cell. Although the frequency distribution of counts measured during this long episode generally corresponded to a Poisson distribution, multiplicities of five or more were registered several times. Close to the peak of the emission episode for example there were more than 20 such high multiplicity cascade events within a time span of 5 minutes (Table VII in Iyengar et al., 1990).

4. Frequency Spectrum Measurements with TiD_2 Targets: A 15 g sample of Ti-ZrD_2 was monitored over the weekend of 9 to 11 June 1989. The He^3 detector bank was the foreground counter while the BF_3 detector was the background monitor. Even though there was no statistically significant increase in average neutron count rate relative to the no target case (0.42 cps), in the presence of the deuterated target the foreground counter (He^3 bank) recorded several high multiplicity (three counts and four counts per 20 ms bin) events whereas the background counter did not register any events beyond doubles.

During the weekend of 17 to 19 June a deuterated Ti metal disc target was monitored. An 85 minute long neutron emission episode occurred (see Figure 1 of Sec 4. in Iyengar et al., 1990) during which it is estimated to have emitted 5×10^5 neutrons in all. Here too several high multiplicity events were registered whereas the corresponding background counter did not record any high multiplicity counts. On the whole this target also gave rise to a significant number of high multiplicity neutron emission events.

In general it is observed that the frequency spectrum of counts follows Poisson distribution for low multiplicity events, but there is a distinct tendency for the spectrum to show a slight peak between the multiplicities of four and six. If we assume that this peak is due to the superposition of bunched neutronic events on a Poisson background, one arrives at an estimate for the value of s to be in the range of 400 to 600. This follows from the fact that the peak of the binomial distribution occurs at the multiplicity value corresponding to the product $\nu\varepsilon$ and ε values in the above experiments were in the region of ~0.01.

5. Burst Neutron Measurements Using the Dead Time Method (1994): Experiments deploying the "artificial dead time" technique were conducted (Shyam et al., 1995) during a 60 day period in the summer of 1994 using a second Milton Roy electrolytic cell procured in 1991. (Initial trials in 1991 with this new cell had not yielded any detectable neutron output.) A noteworthy difference between the 1989 experiments and the 1994 runs, both of which used Milton Roy cells, was that the electrolyte used in the later tests was LiOD (LiOH for "control" runs) instead of the earlier NaOD. Also this time the test cell was mounted inside the central tube of an annular neutron detector set up employing 16 numbers of 50 mm dia × 300 mm long BF_3 neutron counters located inside a plexiglass assembly. The neutron detection efficiency in this set up was ~10%, thereby significantly increasing the probability of detecting more than one neutron out of a bunch of simultaneously emitted neutrons.

Data acquisition was carried out under three conditions: During the first 15 days, only background counts were acquired; the average background rate was ~0.048 cps. During the next 30 days the Milton Roy cell was housed inside the central tube of the annular neutron detector assembly and electrolysis performed. The last 15 days was meant to be a “control” run wherein the cell was operated with LiOH electrolyte. Detailed results are presented in Shyam et al. (1995).

6. Discussion of Dead Time Method Results: The total neutron counts per day with the D_2O cell was found to be consistently ~9% above the background level throughout the month long run. However in the case of the H_2O run, which was conducted immediately after the 30 day D_2O run, the average daily count rate steadily decreased to background level, suggesting the slow replacement of D by H within the Pd cathodes over time. While there was no characteristic spiked neutron emission episode throughout the 30 day duration, there were several events with multiplicities of six and even seven counts in the burst counts data, in the case of both D_2O and H_2O cells. On the whole however the number of burst events was very few, the average values being 7.6, 3.8 and 1.7 bursts per day for the cases of D_2O cell, H_2O cell and background runs respectively.

In these experiments since the overall neutron detection efficiency was ~10%, one can say that approximately 10 neutrons are emitted by the electrolytic cell for every neutron detected. Likewise a multiplicity of four counts during a 100 μs interval implies emission of a burst of roughly 40 neutrons by the cell. Of the 2608 neutrons detected on an average per day in presence of the Pd-D_2O cell, after subtracting the background of 2386, the balance of 222 counts/day can be attributed to the cell. Of this about 14.5 counts per day can be attributed to high multiplicity (>20) burst neutron emission events. Thus the conclusion from the 1994 experiments is that about 6.5% of the neutrons produced by the Milton Roy electrolytic cell can be attributed to high multiplicity (>20 neutrons/burst) events, and the balance 93.5% is produced either as single neutrons (with Poisson distribution) or with multiplicities of <20 neutrons.

7. Conclusions: On the whole there is unmistakable evidence that in the presence of lenr sources there are significant numbers of high multiplicity neutron emission events. Throughout both the 1989 and 1994 campaigns the background counters never registered multiplicities beyond doubles in any interval and the background data strictly adhered to Poisson distribution. There was never any contribution to the higher multiplicity counts from random (Poisson) sources. This very satisfactory behavior gives us confidence that our multiplicity measurements in the presence of lenr sources are trustworthy.

It does however appear that it may not be appropriate to quote a single number for the magnitude of the neutron bursts especially because not all the bursts have the same magnitude. One can only set a sort of upper limit to the number of neutrons emitted in a single burst. In the 1989 experiments when there were many large spike type neutron emission episodes, perhaps the burst size may have been in the region of several hundreds of neutrons. However in the 1994 experiments in which there were no characteristic spike type neutron emission episodes the Milton Roy cell seems to have emitted neutrons steadily throughout a 1 month period. We estimate that approximately 6.5% of these neutrons were perhaps in the form of bursts, but of a smaller size of possibly 20 to 100 neutrons (at most) per burst.

The dead time technique is clearly superior and a great improvement since the analysis interval is only 100 μs as compared to the 20 ms interval used earlier. Also in the dead time method every burst event is captured unlike the multichannel time analyzer method of 1989 where there was a large unutilized time gap between intervals.

What could be the mechanism responsible for the production of such neutron bursts? In view of the importance of this question statistical analysis experiments warrant attempts at replication.

Also it is worth emphasizing that in situations wherein the absolute rate of neutron emission by the lenr source is extremely small in comparison to the background count rate, measurement of high multiplicity events can establish the occurrence of neutron emission in an unambiguous manner. This advantage of neutron multiplicity measurements has not been adequately appreciated by the lenr community during the last two decades!

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