Neutron Emission in Bursts and Hot Spots: Signature of Micro-Nuclear Explosions?

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This paper was presented at the March 2010 New Energy Technology Symposium, a session at the 239th American Chemical Society national meeting in San Francisco, California. The Proceedings will be published in a special edition of the Journal of Condensed Matter Nuclear Science (www.iscmns.org/CMNS/CMNS.htm).

Abstract — Within a few months of the Fleischmann-Pons announcement of 1989, several independent groups at Bhabha Atomic Research Centre (BARC) had confirmed the production of neutrons and tritium in a variety of electrolytic cells. Among the many findings of the BARC groups were the first hint of the neutron to tritium branching ratio anomaly, namely that tritium production is several orders of magnitude higher than that of neutrons, that neutrons and tritium are probably being emitted simultaneously and that at least in the case of titanium targets, the generated tritium is found to be entrenched in highly localized "hot spots." But the most intriguing observation of all was that neutrons appeared to be emitted in sharp bursts of up to 10^3 neutrons per event. An integrated view of all these findings taken together led to the speculation that perhaps up to 10^{10} to 10^{12} tritons each were being generated in the form of micro-nuclear explosions, with neutron emission being only a minor side reaction in the process. Whatever the nature of the phenomenon, it seemed to be occurring in a highly localized fashion, both in space and time.

Since those early days, however, the aspect of spatially localized occurrence of nuclear reactions has gained further acceptance through the concept of the "Nuclear Active Environment." The observation of thermal hot spots, micro-craters and isolated regions wherein transmutation products are concentrated on the cathode surface has reinforced the suspicion that the phenomenon is spatially localized. But how reliable is the evidence for localization in time? This review revisits our early neutron multiplicity measurements since it appears that confirmation of multiple neutron production is possibly the only handle, we have to establish the temporal localization feature and thereby give some insight into the possible occurrence of micro-nuclear explosions which in turn would have a tremendous bearing on the nature of the theoretical mechanism governing these low-energy nuclear reactions (LENR).

INTRODUCTION

Two decades of wide ranging studies has shown that low-energy nuclear reactions (LENR) take place primarily on the surface rather than in the bulk metal. The growing preference for thin films, small diameter wires, nano powders, etc. is an indication of this. Further, there is convergence of perception that even on the surface, these reactions occur only at certain special locations—referred to as the "Nuclear Active Environment" (NAE)[1]—which are thought to be created during the dynamic transport of deuterons (or protons) in and out of the metal, often initiated by some type of triggering mechanism. However, the exact nature of the NAE continues to be elusive.

In the present paper we wish to bring into the conversation the aspect of "localized time," in addition to localized space, governing the occurrence of these reactions. In other words, we raise questions regarding the temporal characteristics of the NAE. It is reasonable to expect that NAEs will not all be created simultaneously and uniformly over the entire host metal surface and also, once created, would not be able to continue catalyzing nuclear reactions "forever." Thus it may be postulated that NAEs are continuously generated and destroyed and during their "lifetime" they trigger a certain number of nuclear reactions. A pertinent question that then arises is: what could be the order of magnitude of the lifetime of the NAEs? Could it be possible that their lifetime is as small as nanoseconds or microseconds?

This line of thinking leads us to postulate that the LENR phenomenon could be comprised of a series of "bursts" of nuclear reactions, each burst composed of "x" number of nuclear reactions generated by an NAE site during its lifetime. What could be the temporal characteristics of the reactions *within* a single nuclear "burst"? Could these individual reactions be "chain correlated," with each new reaction being triggered by the previous one or an "exotic" agent or particle responsible for catalyzing these reactions? Alternately the entire "x" number of reactions could all take place simultaneously in a coherent fashion, in a "flash." In either case it would have the characteristics of a micronuclear explosion.

These speculative considerations are not entirely imaginative but arise out of the multiplicity distribution of neutron counts measurements that BARC carried out during the first few years following the Fleischmann-Pons announcement, with both electrolytically loaded Pd cathodes as well as gas loaded Ti targets. These early measurements led us to conclude, even as far back as 1989,[2] that micro-nuclear explosions are possibly responsible for the generation of tritium in highly localized hot spots. In this paper we first review the sequence of experimental findings that led us to such a conclusion and then go on to examine whether there is any case

for extending the concept of micro-nuclear explosions to other nuclear reactions that have also been observed in the LENR field. An abridged version of the present paper was earlier published in the proceedings of ICCF15 held at Rome in October 2009.[3]

SUMMARY OF THE EARLY BARC FINDINGS

Within days of the Fleischmann-Pons announcement in March 1989, a dozen independent groups from various divisions of BARC set up electrolytic cells using whatever materials were readily available. Clear evidence was obtained for the production of neutrons and tritium, signatures of the occurrence fusion reactions, but with the difference that tritium production was higher by several orders of magnitude as compared to neutrons. A comprehensive overview of these early BARC results in which over 50 researchers were involved has just been republished.[4] The main findings are summarized below.

BARC Finding #1 : Branching Ratio Anomaly

The majority of the BARC cells produced both neutrons and tritium[6] with the neutron to tritium yield ratio being in the range of ~10^{-7} rather than the expected value of unity. BARC groups were among the first to publish[2] this unexpected feature of neutron and tritium production in electrolytic cells. This so-called "branching ratio anomaly" has since been observed by several other groups as well, even using devices wherein the deuterium loading into titanium samples was carried out by gas loading methods. The branching ratio anomaly essentially signifies that on an average one neutron is generated for every 10 million tritons. Surprisingly, neutron and tritium production was also noticed in a couple of instances even after the cell current had been switched off in the case of electrolytic cells or with unperturbed TiD_2 targets just sitting on the table, a behavior which has since come to be alluded to as "heat after death" in LENR literature.

BARC Finding #2 : Simultaneous Production of Neutrons and Tritium

In electrolysis experiments, neutron yield is measured online using standard neutron pulse detector set ups (BF_3 counters, proton recoil type scintillators, etc.), while tritium production is measured offline employing liquid scintillation techniques, with the electrolyte being sampled typically once or twice a day or at times once in a few days. In the BARC experiments it was noted that invariably the tritium levels indicated a jump only after one or more neutron emission "spikes" had been detected. Figures 1 and 2, reproduced from Reference 6, bring out this behavior.

It was inferred from these experiments that neutrons and tritium are probably produced simultaneously. Simultaneity in time would also imply co-generation at the same spatial location as a product of the same event; it is difficult to conceive of a mechanism responsible for concomitant generation from spatially separated sites since otherwise we are faced with an action-at-a-distance problem.

BARC Finding #3 : Multiplicity Distribution of Neutron Emission

BARC groups were the first,[2,7] and perhaps the only group so far, to have carried out a detailed experimental analysis of the statistical characteristics of the neutrons emitted by LENR devices. The question we asked ourselves was: Are the neutrons put out by these devices being emitted one at a time following Poisson statistics or are they emitted in bunches of 2, 10 or 100s? We were inspired to ask such a question primarily because one of us had, decades earlier, carried out a Masters degree thesis study on the neutron density (or flux) fluctuations in a zero energy experimental fission reactor using the so-called Feynman alpha technique.[8] He had the experimental background and familiarity with the statistical analysis methodology to quickly set up the hardware to measure the multiplicity distribution of neutron emission. The details of this are elaborated on further in a later section in view of its central importance to the main theme of the present paper.

The results of neutron multiplicity studies, repeated with many different LENR devices, clearly indicated that a non-negligible fraction (6.5 to 25%) of the neutrons produced were in bunches of 20 to 400, the exact fraction and magnitude of the bunches being dependent on the efficiency of the neutron detection set up, the characteristics of the LENR device and the nature of the deuterium-loaded metal. The intriguing question raised by this finding which has puzzled this author for the last two decades is: What could be the mechanism by which such bunched neutron generation takes place?

Implication of BARC Findings 1, 2 and 3 Taken Together

If for every neutron produced 10 million tritons are generated "simultaneously" and if say 100 neutrons are emitted in a bunch, then it could be logically concluded that 10^9 tritons are produced in the form of a micro-nuclear explosion. In this context we have already considered arguments which suggest that all this must be taking place at a highly localized site, because otherwise we would be obliged to invoke an

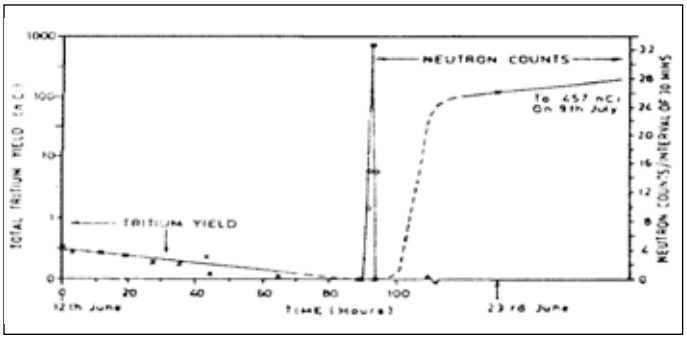

Figure 1. Concomitant generation of neutrons and tritium during run 2 of the first Milton Roy cell.

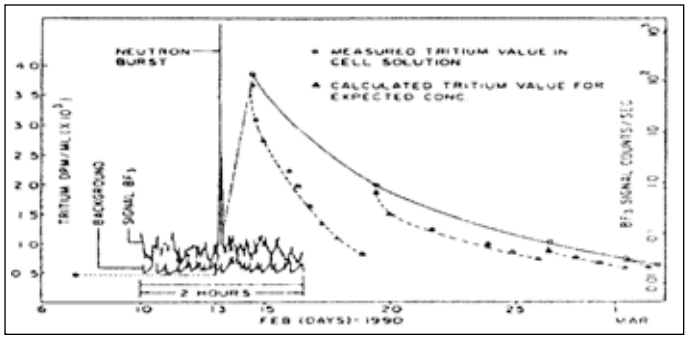

Figure 2. Increase of tritium concentration in electrolyte following a neutron spike in ROMG cell.

appropriate action-at-a-distance mechanism. In the following it is shown that this is precisely what the autoradiographic images seem to indicate.

BARC Finding #4 : Tritium Found Mainly in Hot Spots in Gas-Loaded Ti Targets

BARC groups deployed autoradiography as a very powerful tool to identify the location of tritium embedded in deuterated titanium targets.[9,10] The samples were placed close to but not touching medical X-ray films giving exposure times in the region of 20 to 60 hours. Both deuterium-loaded and hydrogen-loaded palladium and titanium samples were investigated. We also carried out a number of basic studies to understand the mechanism of production of images in photographic films deploying various thin absorbers between the target and the photographic film. Such experiments clearly ruled out the possibility that these images could be artifacts caused by chemical reaction of the metallic sample being in direct contact with the emulsion of the photographic film. Besides, in the case of titanium targets, the presence of tritium in the surface layers of the target could be cross checked by measuring the 4.5 Kev Ti K-α X-ray, as well as the direct measurement of the 18 Kev tritium βs.[11] In the case of Pd samples, however, the threshold for production of Pd K-α X-ray is too high for the 18 Kev tritium βs and only direct counting of the tritium β particles could be adopted.

It was thus conclusively established in a variety of gas/plasma-loaded titanium target experiments that in the case of machined (cold worked) samples, the tritium generated by low-energy nuclear reaction processes is invariably lodged in lattice defect spots and crevices where the metal was subject to severe cold working (along outer edges, for example).[11] The plasma focus anodes, which were subject to several charge discharge shots, in particular gave spectacular images of the top surface.[13] Figure 3 shows both a photograph and an autoradiographic image of the top surface of titanium anode rod TA1.

Figure 4, which gives the autoradiographs of the same rod repeatedly measured again and again over a period of five years, brings out the remarkable reproducibility of the images, indicating that tritium remains entrenched in the same spot in titanium for years together. Similar observations were made in the autoradiographic images of deuterated Ti disc samples and also titanium shavings loaded by gas loading methods.[10] This finding further supports our conclusion that the tritium must have in fact been generated at these "hot spots" and did not migrate and accumulate there after being produced elsewhere.

Thus, as already pointed out, although the first three "BARC findings" alone are adequate to support the micronuclear explosion hypothesis, the characteristic spotty autoradiographic images in titanium further strengthens this speculation.

BRIEF REVIEW OF THE NEUTRON MULTIPLICITY MEASUREMENTS

Basis of Time Resolved Detection of Individual Neutrons of a Simultaneously Emitted Burst

When a bunch of simultaneously produced fast neutrons impinges on a large hydrogenous moderator assembly in which one or more thermal neutron detectors such as BF_3 or He^3 gas proportional counters are embedded, because of the statistical time spread (typically about 25 ⊠s) that occurs during the neutron slowing down process, a certain fraction of the total number of neutrons emitted get separately and individually detected in a time resolved manner, the exact fraction depending on the geometrical efficiency and other factors. The resultant time series of electronic pulses issuing from the neutron detector tubes can then be analyzed for its statistical properties, especially the degree of departure from Poisson characteristics, in order to yield information on the neutron multiplicity spectrum.

Experimental Techniques for Statistical Analysis

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. In the first method the frequency distribution of counts in 20 ms (or 10 ms) time bins was recorded.[7] In each sweep of the pulse train there were 1,000 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 1,000 bin sweep. The duration of the counting interval was set in the 10 ms to 20 ms region and was dictated by the technical specifications of the computerized data acquisition system which was readily available at that time.

The second approach to measuring the statistical characteristics of the pulse train was an adaptation of the "artificial dead time" method[7,13] developed originally for investigating neutron density fluctuations in experimental fission reac-

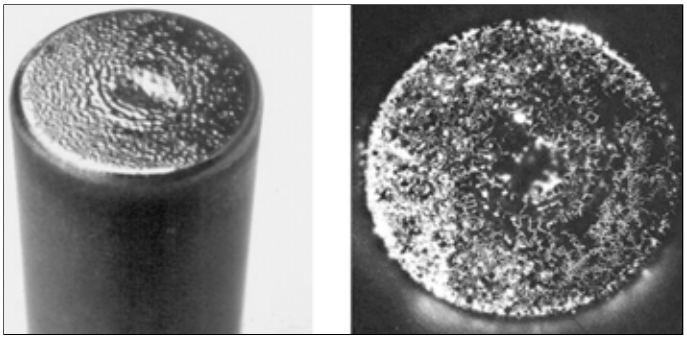

Figure 3. Photograph (left) and autoradiograph (right) of the top surface of titanium anode rod TA1 after 50 discharge shots.

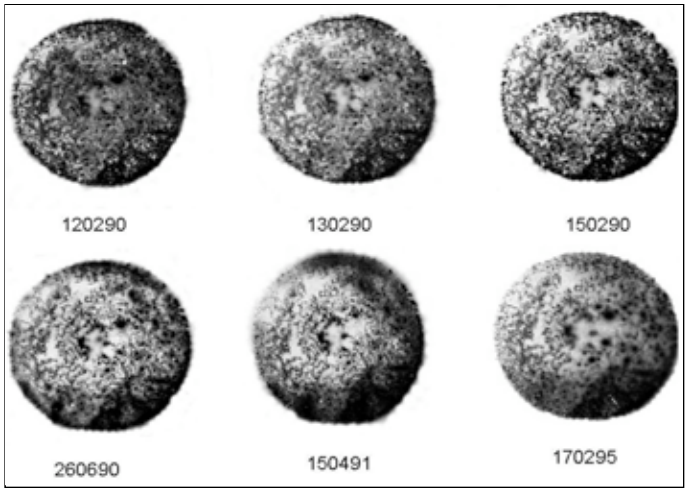

Figure 4. Repeat autoradiographs of titanium anode rod TA1 over five year period. Dates of measurement are given under each radiograph.

tors[8,14] as well as for the passive neutron assay of plutonium in the safeguards field.[15,16] When more than one neutron from a neutron burst is registered by the BF_3 or He^3 detectors (embedded inside a neutron moderator block), the corresponding electronic pulses will all be time correlated and closely spaced within about 100 ⊠s of each other. In such events the second, third and subsequent pulses of the "family of pulses" are diverted by a 100 ⊠s wide "artificial dead time gate" into a separate "burst counts analyzer," while the leading pulses are totalized separately. The computerized burst counts analyzer then carries out a frequency of counts analysis to give the multiplicity spectrum of the neutron counts.

Theoretical Considerations

For a purely random (Poisson) pulse series wherein N_0 is the average count rate and τ is the counting bin time interval (in this case 20 ms) and for the case when $N_0\tau$ is <<1, the probability of registering one count in a single 20 ms interval is $N_0\tau$, while $[(N_0\tau)^2]/2!)$ gives the probability of getting doubles, $[(N_0\tau)^3]/3!)$ that of getting a multiplicity of three counts and so on. Note that the probability of getting higher order multiplicity counts decreases steadily, since $N_0\tau$ is much less than unity.

If now there are ζ burst events per second 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 $\zeta\nu\varepsilon$. The probability of getting *r* counts in time τ from burst events is governed by a binomial distribution. Table 1, reproduced from Reference 17, 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. It is noteworthy that for burst events the peak of the multiplicity distribution actually shifts to higher multiplicity values as the product $\nu\varepsilon$ increases. Thus when the product $\nu\varepsilon$ exceeds unity (as for example when a bunch of 500 neutrons are emitted in a single event and detection efficiency ε is 1.5% in which case the magnitude of product $\nu\varepsilon$ is 7.5) the probability of registering four or five counts per interval could be even higher than that of obtaining doubles or even triple counts, as evidenced from the last column of Table 1.

RESULTS OF NEUTRON MULTIPLICITY MEASUREMENTS

Neutron multiplicity measurements were carried out both with a large cathode area Milton Roy type Pd-D_2O electrolytic cell[3,5] as well as some gas/plasma loaded TiD_2 targets. In these "first attempt" experiments conducted in 1989, only the frequency spectrum type analysis was performed. Unfortunately the overall neutron detection efficiency was only around 1 to 1.5%, primarily due to the poor geometrical arrangement of the detector assembly with respect to the source of neutrons. Table 2 shows the multiplicity distribution of neutron counts of both the foreground and background detector channels taken over a 63 hour background run. It may be seen that no multiplicities beyond doubles were recorded. In general the equipment was found to function very satisfactorily, with the no-LENR-source (background) counts both of the foreground detector as well as the background detector strictly obeying Poisson statistics.

One of the unexpected surprises, however, as already commented upon, was that both a shut off but previously operated electrolytic cell, as well as stand alone TiD_2 targets, emitted neutrons even in an unperturbed state. In all these runs the neutron yield was in the form of distinct spikes superimposed on a steady background.

The first frequency distribution measurements with an operating Milton Roy cell were conducted from June 12, 1989 onwards. An initial neutron emission episode lasting ~5 minutes duration occurred about 30 minutes after commencement of electrolysis and this was followed by two more such episodes about an hour later. The cell current was then switched off (evening of June 14) 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 run period lasting several days, the background counter did not register any noticeable increase in count rate, nor did it record any multiple counts events.

On the evening of June 16, an extended 2.5 hour long neutron emission episode occurred 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 (between 19.45 to 19.55 hrs). Even the background neutron monitor which was 1.5 m away indicated a significant increase in count rate, commensurate with its efficiency for neutrons emanating from the Milton Roy cell. Table 3 presents the frequency distribution of neutron counts measured during this long episode. It

Table 1. Theoretical prediction of frequency distribution of counts for random (Poisson) and burst neutron events for typical sets of experimental parameters.

Multiplicity Of counts	Frequency of Counts in 20ms Intervals for 10^5 samples					
	Poisson Events		Bunched Events ($S=10^{-2}$ per sec)			
	N_0=0.3 cps	N_0=3.0 cps	ν = 100	ν = 100	ν = 500	ν = 500
			ε = 0.005	ε = 0.015	ε = 0.005	ε = 0.015
			$S\nu\varepsilon$ = 0.005	$S\nu\varepsilon$ = 0.015	$S\nu\varepsilon$ = 0.025	$S\nu\varepsilon$ = 0.075
0	99940	99402	99992	99984	99980	99980
1	60	597	6.1	6.6	4.00	0.07
2	$\sim10^{-2}$	1.7	1.5	5.0	5.1	0.3
3	$\sim10^{-9}$	$\sim10^{-2}$	0.2	2.5	4.2	0.8
4	$\sim10^{-9}$	$\sim10^{-3}$	0.03	1.0	2.6	1.5
5	$\sim10^{-13}$	$\sim10^{-5}$	0.003	0.33	1.3	2.2

Table 2. Experimentally observed multiplicity spectrum of background counts in two different neutron detector channels over a 63 hour period, counting interval 20 ms.

Multiplicity of counts	Frequency	
	BF_3 Bank	He^3 Bank
0	750035	743948
1	339	6413
2	1	14
3	0	0
4-20	0	0
N_0	0.023cps	0.43cps
$N_0\tau$	5×10^{-4}	0.0086

may be seen that multiplicities of even five or more were registered several times. Close to the peak of the emission episode, for example, there were almost 20 such high multiplicity burst neutron emission events within a time span of 5 minutes (see data of 19.55 hrs). A fresh attempt at neutron multiplicity measurements was made in the summer of 1994 with a newly procured Milton Roy cell. This time the electrolyte used was LiOD instead of NaOD which was used in the 1989 runs. (The manufacturer had actually recommended only NaOD. This is being emphasized since use of LiOD could have had a bearing on the neutron production characteristics of the new Milton Roy cell.) We used a large annular neutron detector set up inside the central tube of which the electrolytic cell was mounted giving a neutron detector efficiency as high as ~10%. For statistical analysis of the pulse train the improved artificial dead time technique discussed earlier was employed. The experiment was conducted over a two month period. The first 15 days were used to collect background data. The second one month was devoted to data collection with the operating new Milton Roy cell charged with LiOD electrolyte. For the last 15 day run LiOD electrolyte was replaced by LiOH. (We thought we were doing a control run, but it turned out that the Pd cathodes were probably still charged with deuterium from the previous one month's LiOD run, as we shall see shortly.)

The variation of the neutron counts over the two month period clearly showed that with the LiOD electrolyte the average neutron count rate was systematically ~10% above the background values recorded during the no cell run of first 15 days.[13] But surprisingly during the last 15 days when the electrolyte had been replaced with LiOH, the counts did not fall to background values immediately but rather decreased steadily over the next 15 day period, eventually attaining background levels, suggesting that it took 15 days for the deuterium inside the Pd cathode to be fully replaced by hydrogen. Figure 5, reproduced from Reference 13, presents the variation of the burst neutron counts component over the 60 day period as detected by the dead time technique discussed above. This too shows evidence of the slow replacement of D by H during the last 15 days.

Figure 6 presents the variation of the total integrated number of neutrons which were detected as bursts, observed over the entire 15 or 30 day period, as a function of the neutron multiplicity (15 day counts have been normalized to 30 day period for comparison). Here again the counts data during the third phase with LiOH electrolyte clearly displays evidence of significant non-Poissonian multiplicity, due to deuterium still being embedded within the Pd metal.

Detailed descriptions of all these measurements and results are available.[2-7,13,17] In all these runs the foreground counter gave clear evidence of several higher order neutron multiplicity events. In many instances during the 1989 measurements, the peak of the multiplicity spectrum was in the 4 or 5 neutron pulses region. Since the overall neutron detection efficiency in those runs was only ~1% it implies that approximately 400 to 500 neutrons were produced in each of those "explosive bursts." In fact, during the June 16, 1989 run with the first Milton Roy cell wherein the 2.5 hour long neutron spike episode occurred, multiplicities as high as 15 were recorded during the last 5 minute interval (see Table 3), implying that a burst of 1,500 neutrons was produced in this flash incident.

In the 1994 campaign during the D_2O run with the new Milton Roy cell, in spite of the higher (~10%) neutron detection efficiency, the maximum multiplicity recorded was only around 8 counts, pointing to a burst strength of not more than 80 neutrons. It must, however, be noted that in this experiment the average magnitude of the neutron output was only ~10% above the background values and there were no clearly distinguishable spikes superimposed on the background values. In response to a possible criticism that a mere 10% above background levels could be "suspect," it may be pointed out that the observation that when the LiOD was replaced with LiOH the neutron count rate steadily decreased to background values over a 15 day period clearly confirms that the neutrons were indeed produced by LENR processes.[13]

DISCUSSION AND CONCLUSIONS

Thus on the whole there is unmistakable evidence that

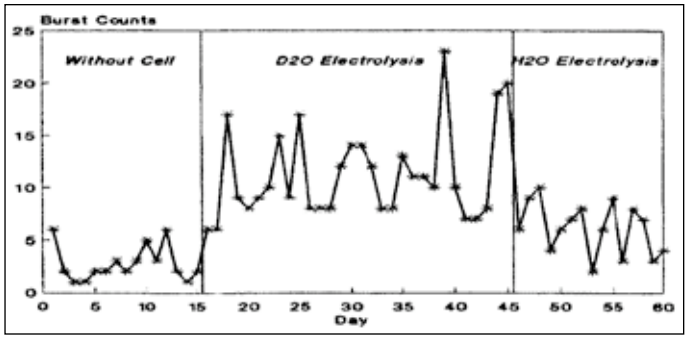

Figure 5. Daily variation of sum of burst component of neutron counts.

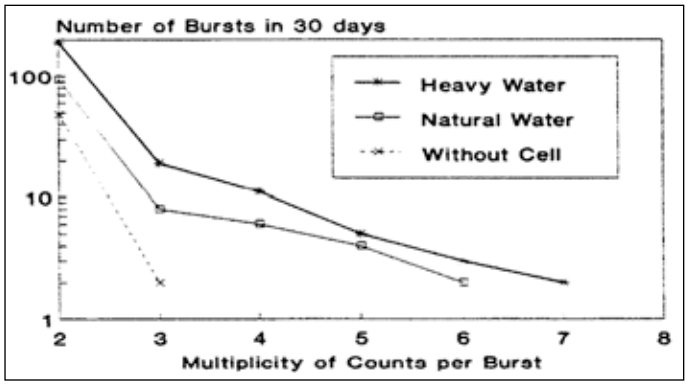

Figure 6. Variation of total number of counts of neutron pulses which passed through dead time gate over 30 day period as a function of multiplicity.

Table 3. Multiplicity distribution of neutron counts in 20 ms time bins from a quiescent Milton Roy cell: neutron emission episode of June 16, 1989.

Time	BF_3 Counter Bank (Signal)															^{3}He Counter Bank (Background)		
(Hrs)	1*	2*	3*	4*	5*	6*	7*	8*	9*	10*	11*	12*	13*	14*	15*	1*	2*	3*
18.55	124	21	4	1	-	-	-	-	-	-	-	-	-	-	-	2	1	-
19.00	54	9	1	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
19.05	335	54	7	2	1	-	-	-	-	-	-	-	-	-	-	4	-	-
19.10	320	82	10	-	-	-	-	-	-	-	-	-	-	-	-	5	-	-
19.15	243	13	4	-	1	-	-	-	-	-	-	-	-	-	-	5	-	-
19.20	315	35	3	1	-	-	-	-	-	-	-	-	-	-	-	4	-	-
19.25	295	24	-	1	-	-	-	-	-	-	-	-	-	-	-	5	-	-
19.30	492	51	3	2	-	-	-	-	-	-	-	-	-	-	-	4	-	-
19.35	447	42	2	1	-	-	-	-	-	1	-	1	-	-	-	9	-	-
19.40	104	13	4	-	-	1	-	-	-	-	-	-	-	-	-	5	-	-
19.45	355	49	1	1	-	1	-	-	-	-	-	-	-	-	-	33	1	-
19.50	395	99	16	2	-	-	-	-	1	-	-	-	-	-	-	22	3	-
19.55	55	24	7	33	2	1	1	1	1	1	2	2	1	-	5	6	2	-

(*) Starred numbers represent the multiplicity of counts obtained in a single 10 ms interval. The respective frequency of occurrence (per 1000 gated intervals) is given in the corresponding column below.

whenever LENR sources produce neutrons, a considerable fraction (6.5% to 25%)[6,12] of these are emitted in the form of bursts of strength varying from 20 to several hundred, the exact magnitude depending on the type of LENR source. The neutron detection efficiency (ε), however, sets a lower limit to the magnitude of the burst strength that can be detected. For example, if ε is only 1% and one neutron count is registered during a one minute interval, this could have resulted either from 100 isolated events of single neutron emission during that one minute interval or from a single burst of 100 neutrons, on account of the 1% detection efficiency. In other words, it is possible that the balance of 75% to 93.5%, although registered as singles counts, could still have resulted from burst neutron emission. This is a point that is seldom appreciated. Thus it would seem that the real fraction of neutrons emitted as bursts could have been much larger than the figures quoted above.

We are proposing in this paper that each of the hot spots wherein tritium was found to be concentrated could perhaps be associated with an NAE site of the type discussed in LENR literature.[1] Based on the BARC findings we therefore postulate that once an NAE is formed, a rapid cascade of up to 10^{12} tritium producing nuclear reactions takes place in quick succession in this local site, in a sort of micro-nuclear explosion, during which process on an average for every ten million tritium nuclei generated one neutron is also emitted as a very low probability offshoot side reaction event.

We then go on to further speculate that if neutrons and tritium could be produced in micro-nuclear explosions then possibly other nuclear reactions such as those responsible for heat and helium as well as transmutation products could also possibly take place in similar micro-nuclear explosions. As noted earlier, the observed craters in post-run cathodes could be an indication of such events.

Indeed, as noted by Krivit[18] recently, there have been several unexplained "excess heat boil off" incidents accompanied by significant energy release reported in LENR literature over the last two decades, starting with a major explosion/meltdown incident involving a 1 cm^3 Pd cathode that Fleischmann has discussed, all of which seem to suggest that "runaway mini nuclear explosions" have all along been suspected to happen in Pd samples heavily loaded with deuterium, but only on very rare occasions. A widely circulated but unpublished recent assessment of the LENR field carried out by the U.S. Defense Intelligence Agency[19] has even raised the question: "If rapid explosive energy output can occur in one or several modes, could LENR serve as a high-energy density explosive?"

In conclusion, it is once again emphasized that the main experimentally measurable parameter that can throw more light on these speculations is neutron multiplicity and hence statistical analysis experiments of the type described in this paper warrant serious attempts at replication. The key to successful observation of neutron multiplicity is, however, obtaining high neutron detection efficiency and use of the dead time method in conjunction with thermal neutron detectors embedded inside a neutron moderator block.

We do concede that our "claim" of simultaneous production of neutrons and tritium is a weak link in the arguments used to arrive at the micro-nuclear explosion hypothesis and certainly that too needs independent confirmation through further careful measurements.

ACKNOWLEDGEMENTS

The author wishes to place on record the significant contributions of his former colleagues and co-authors of many of the BARC papers referred to here, notably Drs. P.K. Iyengar, S.B. Degwekar, A. Shyam, T.C. Kaushik, R.K. Rout and L.V. Kulkarni.

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