Hot Spots, Chain Events and Micro-nuclear Explosions

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Abstract. In 1990 the BARC group presented results at several fora, based on our neutron multiplicity studies as well as tritium measurements, that suggested micro-nuclear explosions seem to occur at localized hot spots in which both Tritium and neutrons are generated, subject to the n/T branching ratio anomaly. It was estimated that about 10^8 to 10^{10} tritium generating lenr reactions take place in these hot spots accompanied by a very small fraction of neutrons. During the last few years several researchers have reported detecting a variety of transmutation reaction products in localized sites, often associated with some type of crater formation. Other experimenters have reported online detection of flashes of "thermal hot spots" in their cathodes. It is therefore tempting to speculate that perhaps the concept of micro-nuclear explosions can be extended to heat generating helium producing reactions too, as well as nuclear reactions responsible for transmutation products. Many theoretical models such as those that depend on the catalyzing role of some exotic intermediate agent (such as Bose-Einstein condensates, deuteron clusters, Erzions, poly neutrons, trapped neutrons etc) seem to point to the possibility of occurrence of chain events. Two decades into the CMNS era, it is therefore worthwhile re-examining the merits of the micro-nuclear explosion hypothesis and seek independent experimental evidence to either corroborate or refute such a hypothesis.

1. Summary of the early BARC findings

Two decades of wide ranging research has shown that low energy nuclear reactions take place primarily on the surface rather than in the bulk metal, the growing preference for thin films, small diameter wires and nano powders being 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 "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 "localised time" in addition to localised 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 for "ever". 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 duration of the lifetime of the NAEs ? Could it be possible that their lifetimes is as small as nanoseconds or microseconds?

This line of thinking leads us to postulate that the lenr phenomenon could comprise of a series of "bursts" of nuclear reactions, each burst composed of "x" numbers 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 or an "exotic" agent or particle responsible for catalyzing these reactions? Alternately the entire "x" numbers of reactions could all take place simultaneously in a coherent fashion, in a "flash"; In either case we are presented with a micro-nuclear explosion!

These speculative considerations are not entirely imaginative but arise out of the multiplicity distibution of neutron counts measurements that our group had 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 localised 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 been observed in the lenr field.

2. Summary of the early BARC findings

Within days of the Fleischman-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 review of these early BARC results in which over 50 researchers were involved [3] has just been re-published [4]. The main findings are summarised below :

2.1 BARC finding # 1 - Neutron to tritium branching ratio: Majority of the BARC cells produced both neutrons and tritium [5] 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 also, inclusive of with devices where in the deuterium loading into titanium samples was effected 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 unpurturbed TiD_2 targets just sitting on the table, a behaviour which has since come to be alluded as "life after death" in CMNS literature.

2.2 BARC finding # 2 - Simultaneity of 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 off line 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. Figs 1 & 2 reproduced from Reference [5] bring out this behavior.

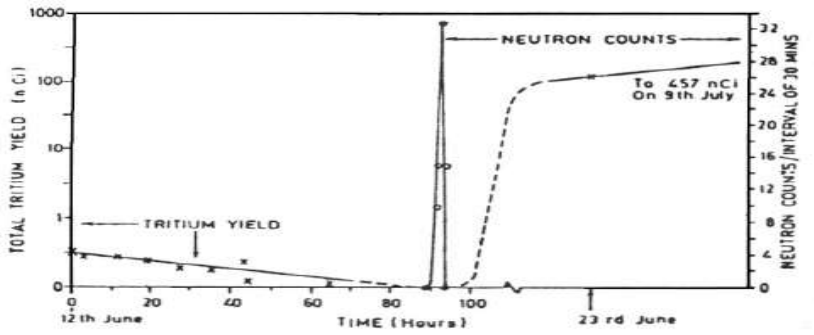

Fig. 1 - Concomitant generation of neutrons and tritium during run 2 of the first Milton Roy cell.

It was inferred from these 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, since 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.

2.3 BARC finding # 3 - Multiplicity distribution of neutron emission: BARC groups were the first [2,6] 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 thesis study on the neutron density (or flux) fluctuations in a zero energy experimental fission reactor using the so called Feynmann alpha method [7]. He had the experimental background and familiarity with the statistical analysis methodology readily available to quickly set up the hardware to measure the multiplicity distribution of neutron emission. The details of this are elaborated on further in Section 3 below in view of its central importance to the main theme of the present paper.

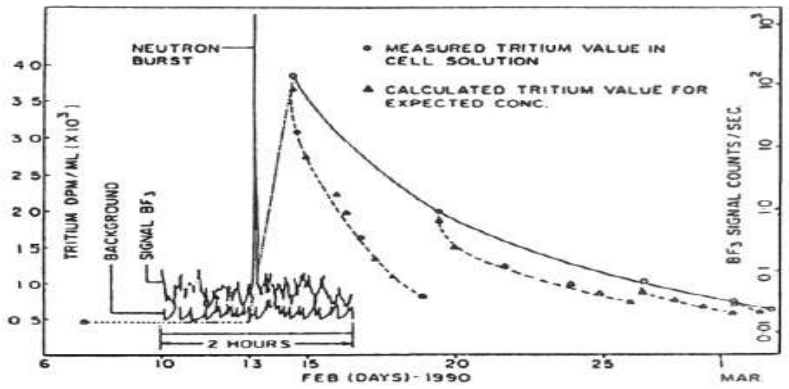

Fig. 2 - Increase of tritium concentration in electrolyte following neutron burst in ROMG cell.

The results of neutron multiplicity studies, repeated on many different lenr devices, clearly indicated that a non negligible fraction (6 to 15%) 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 type of the deuterium loaded target 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?

2.4 Implication of BARC findings 1, 2 and 3 taken together: If for every neutron produced 10 million tritons are generated "simultaneously" and if say a 100 neutrons are emitted in a bunch then it could be surmised 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 appropriate action-at-a-distance mechanism. In the following it is shown that this is precisely what the autoradiographic images seem to indicate.

2.5 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 [8]. 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 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 [9]. 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 needs to be adopted.

It was 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 (edges for example) [10]. For example the plasma focus anodes which were subject to several

charge discharge shots in particular gave spectacular images of the top surface [11]. The auto-radiographic images of rod TA 1, repeatedly measured again and again over a period of five years were remarkably reproducible showing that tritium remains entrenched for years in the same spot in titanium . This observation is indicative of the fact that the tritium must have been produced at these spots and could not have migrated and accumulated there after being generated elsewhere.

Thus as concluded in sec 2.4 the first three BARC findings alone are adequate to support the micro-nuclear explosion hypothesis. But the spotty autoradiographs in titanium further strengthens this speculative hypothesis.

3. Brief review of the neutron multiplicity measurements

3.1 Basis of time resolved detection of individual neutrons of a simultaneously emitted bunch:
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 statatistical time spread (typically about 25 μs) that occurs during the neutron slowing down process, a certain fraction of the total number of neutrons emitted would 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 set up can then be analysed for its statistical properties, especially the degree of departure from Poissonian nature, in order to yield information on the neutron multiplicity spectrum.

3.2 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 time bins was recorded [6]. 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 [6,12] developed originally for investigating neutron density fluctuations in experimental fission reactors [7,13] as well as for the passive neutron assay of plutonium in the safeguards field [14,15]. 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. The computerized burst counts analyzer then carries out a frequency of counts analysis to give the multiplicty spectrum of the neutron counts.

3.3 Theoretical considerations[16] :
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 I of ref. [16] 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. It is noteworthy that 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% in which case the magnitude of νε is 10) the probability of registering three or four counts per interval could be even higher than that of singles or doubles counts!

4. Summary of neutron multiplicity measurement results

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. In general we were happy to note that the equipment functioned very satifactorily, with the no source background counts both of the foreground detector as well as the background detector strictly obeying Poisson statistics. Never were multiplicities beyond doubles ever recorded in background runs. One of the unexpected surprises, as already commented upon, was that both a shut off but previously operated electrolytic cell, as well as stand alone TiD_2 targets, produced neutrons even in an unpurturbed state. In all these runs the neutron yield was in the form of distinct spikes superimposed on a steady background.

The 1994 campaign was conducted with a newly procured Milton Roy cell. This time the electrlolyte used was LIOD instead of NaOD which was used in the 1989 runs. (The manufacturer 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 location 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 a two month period : The first 15 days were used to collect background data. The second one month was with the fully operating Milton Roy cell in place ; 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 probably still had deuterium loaded from the previous one month run. It was evident from the neutron counts data that the deuterium was slowly getting replaced with hydrogen over the 15 day period.

Detailed descriptions of all these measurements and results are available in refs. [2 to 6, 12,16]. In all the runs the foreground counter gave clear evidence of several higher order neutron multiplicity events. In some cases in the 1989 campaign the peak of the multipilicity spectrum was in the 4 or 5 neutron pulses region. Since the overall neutron detection efficiency in those runs was only ~ 1 % this would imply that in these runs approximately 400 to 500 neutrons were produced in each of the "explosive bursts". In the 16th June 1989 run with the first Milton Roy cell for example wherein a two hour long neutron spike episode occurred multiplicities as high as 15 were recorded during the last 5 minute interval, implying that a burst of 1500 neutrons was produced in a flash incident.

ln the 1994 campaign during the D_2O run with the new Milton Roy cell in spite of the higher 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 when the LiOD was replaced with LiOH the neutron count rate steadily decreased to background values over a 15 day period confirming that the neutrons are indeed produced by lenr processes [12].

5. Discussion and Conclusions

On the whole there is unmistakable evidence that whenever lenr sources produce neutrons, a significant fraction (6.5% to 25%) [6,12] of these are emitted in the form of bunches of magnitude varying from 20 to several hundreds, the exact magnitude depending on the type of lenr source. In this context it is however worth emphasizing that, for example, if the neutron detection efficiency ϵ is say 1 % and one neutron count is registered it could still have resulted from a single burst of 100 neutrons on account of

the 1% detection efficiency! Thus the balance 75% to 93.5 % which although detected as singles counts could still have resulted from bunched neutron emission. The key to successful observation of neutron multiplicity is high neutron detection efficiency and perhaps use of the dead time method.

We are suggesting that each of the hot spots where tritium was found to be concentrated in our measurements could perhaps be associated with an NAE site discussed in lenr literature [1]. Based on the BARC findings we therefore postulate that once an NAE is formed a rapid cascade of 10^8 to 10^{10} tritium producing nuclear reactions takes place in rapid succession in this local site, in a sort of chain or cascade event, 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.

However we emphasize that the main experimentall measured parameter fuelling all these speculations is neutron multiplicity and hence statistical analysis experiments of the type described in this paper warrant attempts at replication.

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