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ABSTRACTS

New Energy Technology Symposium Proceedings on Low Energy Nuclear Reactions

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Introduction and Overview

In 1989, the subject of "cold fusion" was announced with great fanfare, to the chagrin of many people in the science community. However, the significant claim of its discoverers, Martin Fleischmann and Stanley Pons, that excess heat without harmful neutron emissions or strong gamma radiation, involving electrochemical cells using heavy water and palladium, has held strong.

In recent years, low energy nuclear reaction (LENR), within the field of condensed matter nuclear science, has begun to attract widespread attention and is regarded as a potential alternative and a renewable energy source that confronts climate change and energy scarcity. The aim of the research is to collect experimental findings for LENR in order to present reasonable explanations and a conclusive theoretical and practical working model.

The goal of the field is directed toward the fabrication of LENR devices with unique commercial potential demonstrating an alternative energy source that does not produce greenhouse gases, long-lived radiation, or strong prompt radiation. The idea of LENR has led to endless discussions about the kinetic impossibility of intense nuclear reactions with high coulomb barrier potential. However, recent theoretical work may soon shed light on this mystery.

Understanding this process is one of the most challenging and perhaps important issues in the scientific world. This review includes previously unpublished studies—new and controversial theories on LENR with access to new sources and experimental results. It offers insight into this controversial subject and will help the audience re-evaluate their perspective on LENR as a possible alternative energy source.

Background

It is obvious that cold fusion is not similar to thermonuclear hot fusion processes. An appreciable number of available documents report on various methods

by which nuclear reaction is produced and controlled at normal temperatures. The experimental methods to achieve this goal range from the use of gunpowder and a laser technique to attempt to electrochemically induce nuclear fusion and fission with significant excess heat within the palladium metal lattice exposed to a solution containing deuterium.

Palladium is very well known to absorb large quantities of hydrogen/deuterium into the bulk metal where the nuclei, electrochemically inserted, occupy interstitial octahedral/tetrahedral sites dependant on the specific palladium–hydride phase. Using this approach, Martin Fleischmann raised the idea of electrochemically inserting deuterium into bulk palladium to a large extent, hoping to increase the probability of deuterium nuclei reacting and colliding efficiently. Based on this idea, in 1989 in Salt Lake City, Utah, Martin Fleischmann together with his colleague Stanley Pons designed an experiment involving an electrochemical cell using a heavy water solution with the corresponding electrolyte and palladium as the electrode in order to generate nuclear fusion within the metal lattice. The energetic output generated after a long-term electrolysis—over a couple of days—was found to be significant. From this, Fleischmann concluded that nuclear fusion of deuterium nuclei inside the bulk palladium metal had occurred. Because this reaction, initially named "cold fusion", seemed to offer an opportunity to solve energy problems in the future, it instantly raised widespread attention. As a result, many very quickly came to regard "cold fusion" as one of the most important topics confronting the scientific community. However, interest in the subject declined just as rapidly because of the phenomenon's lack of reproducibility. This attitude was bolstered by the common opinion, based on conventional physics, that deuterons are very unlikely to collide efficiently at room temperature because of the enormous amount of energetic input needed to overcome the coulomb activation barrier. As a result, the scientific community generally dropped this subject, often heaping scorn on the remaining scientists who expressed an interest in the subject and who continued with their experiments.

The few scientists left in this field have worked constantly over 20 years to replicate the Pons-Fleischmann experiment, to determine and evaluate the experimental parameters that may play a significant role in this process, and to give a plausible theoretical explanation for the results. Given their negligible budgets, the work they have done and the understanding they have acquired of the "cold fusion" process is especially impressive when compared with the standard set by the results obtained by thousands of generously funded scientists working in the "hot fusion" field.

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The following abstracts from the New Energy Technology Symposium provide an overview of experimental and theoretical research performed over the last

19 years. They also offer profound and unambiguous evidence for LENR, historically known as "cold fusion". In the experimental papers presented, the reader is given clear evidence of excess heat, tritium and neutron emission, helium production, and nuclear transmutation of the host metal. In the theoretical papers presented, the reader is given a variety of reasonable explanations, thereby advancing his or her understanding of the experimental results. Some authors also discuss how to design so-called LENR devices based on the experimental results obtained over the years.

Low-Energy Nuclear Reactions Research: 2008 ACS Update

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Introduction: A science journalist's view of the field of low-energy nuclear reactions (LENRs), historically known as "cold fusion," is presented. The author has investigated innumerable aspects of this controversial subject, including its strengths and weaknesses (Krivit, 2008a,b; Krivit & Marwan, 2009; Krivit & Winocur, 2005). He has engaged proponents and opponents alike and provides a balanced understanding and view of the field.

LENR Topics to Be Discussed in This Talk:

- Terminology
- Brief History
- Strengths and Weaknesses of Fusion Claim
- Strengths and Weaknesses of Weak-Interaction Claim

Terminology: The phrase LENR describes the observations in the field of condensed matter nuclear science.

The term "cold fusion" is no longer applicable. One reason is that the term implies that these reactions are a "colder" form of conventional thermonuclear reactions, which they are not. Another reason is that other, nonfusion reactions have been observed in addition to the possible fusion reaction.

LENR includes the effect introduced at the University of Utah in 1989 by Martin Fleischmann and Stanley Pons—which transmutes deuterium, in the presence of palladium, into heat and helium-4—as well as heavy-element transmutation research and experiments that show signs of low-level neutron production.

Brief Update on History of Field: The U.S. Department of Energy reviewed the field very early on, within the first few months of the University of Utah announcement. The government's decision not to fund the research was made by advisers to U.S. President George H. W. Bush before the review.

In 2004, in response to a request by several researchers in the field, the Department of Energy took a second look. The department called it a review of LENRs. The reviewers' responses were mixed. The department did not fund any research.

Despite the lack of interest from the Department of Energy, 20 years later, evidence for the reality of new energy-releasing nuclear reactions is plentiful in the relevant literature. A large part of the conflict and confusion surrounding the topic has been the result of some researchers' claims that the LENRs are a new form of fusion.

That argument—about the underlying mechanism or mechanisms responsible for the observed phenomena—remains open. However, the arguments about the validity of excess-heat measurements, nuclear products, emissions and effects are, in this author's opinion, beyond question.

Strengths and Weaknesses of Fusion Claim: The evidence for the production of helium-4 in experiments with deuterium is rigorous. The helium-4 claims have stood for 14 years. Many experiments show the energy released concurrently with the production of helium-4 within the range that is expected from the mass deficit of two deuterons.

A near-quantitative correlation of energy to helium-4 has occurred on at least one occasion. Michael McKubre of SRI International has proposed that the reason the precise quantitative correlation has been observed infrequently is that helium-4 is being retained in the palladium lattice.

McKubre tested the retention idea once and obtained a mass balance close to 24 MeV per helium-4 atom. However, in another experiment, Danielle Gozzi, with the University of Rome, melted the cathode and found no retained helium-4 in the palladium at the detection limit. The helium-4 retention proposal remains speculative.

Several facts contradict the fusion claim or, at a minimum, contradict the association of the phenomena observed in LENR with thermonuclear fusion. They follow:

1. Missing or suppressed gamma
2. Wrong neutron-to-tritium ratios
3. Wrong ^{4}He-to-neutron ratios
4. Missing first branch of thermonuclear fusion
5. Missing second branch of thermonuclear fusion
6. Weak data for 24 MeV energy (wide range of data, incomplete assay)
7. Heavy element transmutations
8. Normal water and hydrogen experiments

Some theorists speculate that a new type of fusion may be occurring. Their models describe a process by which neutrons are captured by a nucleus, and this process is leading to the formation of new elements.

They suggest that this process is a new type of fusion, in the general sense, of two particles coming together to form a new element. This speculation lacks

credibility because it attempts to twist the very clear, well-accepted understanding of fusion: a process in which like-charged atomic nuclei overcome the Coulomb barrier (electromagnetic force) and get close enough so that the strong force pulls them together.

Strengths and Weaknesses of Weak-Interaction Claim: An alternative mechanism, relying on the weak interaction, has been proposed to explain the production of helium-4, excess heat with both heavy and light water, heavy-element transmutation and a variety of other phenomena observed in LENR.

Weak interactions, using neutron capture processes, have the advantage of not needing to explain how the Coulomb barrier is overcome at low temperatures. As well, by not claiming a fusion reaction, researchers postulating neutron capture processes do not have to resolve the "three miracles" proposed by John Huizenga of the University of Rochester.

Huizenga's three miracles are:

- the lack of strong neutron emissions
- the mystery of how the Coulomb barrier is penetrated
- the lack of strong emission of gamma or x-rays

One of the weak-interaction theories, proposed by Allan Widom and Lewis Larsen, relies on neutron formation from electrons and protons/deuterons, followed by local neutron absorption and subsequent beta-decay processes.

The authors have shown a relationship between their model and some of George Miley's (University of Illinois) transmutation data. They suggest that their model can explain both the transmutation data of Yasuhiro Iwamura (Mitsubishi Heavy Industries) and energy production from hydrogen and deuterium experiments.

The weak-interaction models are not widely supported in the LENR field; most LENR researchers are skeptical. Outside the LENR field however, the weak-interaction models are showing strong signs of acceptance.

Low levels of neutron emissions, which may be the result of secondary reactions, have been observed throughout the 20-year history of the field—most recently, as published by researchers at the Space and Naval Warfare Systems Center in San Diego, Calif. (Mosier-Boss et al., 2008).

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Understanding Low Energy Nuclear Reactions

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When we started our research at ENEA, we were interested in repeating the Salt Lake City experiment and maybe introducing some modifications in order to better understand the phenomenon described by M. Fleischmann and S. Pons (1989). It was soon clear that the major problem was that of the lack of reproducibility and that it must be faced with a better insight of the problem.

After an attempt to obtain the reaction in titanium shavings loaded with deuterium gas, which didn't lead to clear evidence because of a very great irreproducibility (De Ninno et al., 1989), we decided to follow more closely the Fleischmann-Pons model, changing a little bit the calorimetry as compared to their design (Bertalot et al., 1992), in order to improve the precision of the heat evaluation. Sporadic results pushed us to change some times the form of the electrodes and the method of loading (De Ninno & Violante, 1992). In the meanwhile, we decided to study in depth the palladium metallurgy and managed to obtain a clear relationship between some metallurgic features and the maximum obtainable loading (De Ninno & Violante, 1994). This improvement increased the reproducibility of the heat excess measured in the electrolytic cells but, specially, definitively made clear the existence of a threshold in the loading ratio, as already stated by several scientists (Preparata, 1990). At that time the problem of ^{4}He detection was still away to be approached in our laboratory because such a difficult measure requires a much better control on the experiment than we had at that time. The extreme difficulty in discriminating the helium produced in the electrolytic cell from the helium contained in the environment (about 5 ppm in air) didn't consent to be confident in a measure still too much erratic. A further improvement was the decision to work on thin films of palladium as cathodes of electrolytic cells. It was soon clear that the deposition procedure allows a very good control of metallurgy and limited the effect of the so called "Gorsky effect" (De Ninno et al., 1997), that is, the repulsion force generated into the Pd cathode because of the deformation of the lattice due to the H or D uptake. Even though the reproducibility of the effect was increased with respect to the use of massive samples, there still was a percentage (30–40%) of experiments in which the loading didn't reach the threshold and then the effect didn't show (De Ninno et al., 1998).

The real breakthrough was the approach to the Pd-D physics proposed by G. Preparata, who suggested that the peculiar behaviour of Pd-H(D) points towards the existence of a strong cooperation among protons in metal (Bressani et al., 1989). However, this is hardly understandable in the frame of the usual lattice dynamics (Preparata et al., 1996), thus, one could consider the possibility that a macroscopic ensemble of oscillating hydrogen could be described by a unique quantum state created by the collective dynamics. Should this point of view be correct, a testable consequence would emerge: a quantum system, whose

dynamics is described by a unique wave function, is able to "see" an externally applied potential. This effect is the well known Böhm-Aharonov effect (Aharonov & Böhm, 1959); the dynamics of a quantum system is affected by a change of the electromagnetic potential through a modification of the phase of the wave function. Should the ensemble of hydrogen atoms be in an unique quantum state, the chemical potential μ of $H^+(D^+)$ in Pd would be shifted by the applied electric potential $V(\vec{r})$ multiplied by the screened charge Z*e.

The profile of the chemical potential μ is changed in such a way that the chemical potential in some regions of the system can fall below the chemical potential μ_{ext} of the ions outside. Consequently, an inflow of ions would occur in those regions. This effect would be increased if it is possible to apply a large electric potential difference across the system without inducing sizeable Joule heating which could inhibit the precondition for the effect, i.e. the $H^+(D^+)$ coherence. The optimal effect is expected in one-dimensional specimen whose resistance $R = \rho(l/S)$ is increased as much as possible by taking a large length l and a very small cross-section S. This led us to consider a specific geometry for our cathodes and allowed us to increase the loading by a factor of 1.3–1.4 with respect to a two or three dimensional specimen (plate or rod) under identical conditions (Cola et al., 2000).

These new experimental conditions made finally possible the ^{4}He measure because the "Cohn-Aharonov" effect allowed us to control the loading and, at the end, the excess heat generation. In the meanwhile an "ad hoc" mass spectroscopy detector was built up (Frattolillo et al., 2007) and tested in several experiments in which ^{4}He was measured over the background. Whenever we had the possibility to control the loading in the most of the experiments, we had the chance to make a trustworthy correlation in "real time" among loading, excess heat and ^{4}He (De Ninno et al., 2008).

From the theoretical point of view, the study of the literature on Pd-H(D) systems and of some almost forgotten fact in solid state and nuclear physics allowed us to build a framework for the low energy nuclear reactions.

In 1983 Martin Fleischmann had the intuition that nuclear transformations of D^+ compressed into Pd lattice would differ substantially from the reactions observed in dilute plasmas. This intuition was later on shared by Julian Swinger in 1989 (Swinger, 1990).

Even Bridgman in the 1930s (Bridgman, 1947) found that the energy stored in a lattice by intense shear and compression could be released in "cold explosions" in which the stored energy was converted into the kinetic energy of fragments of the lattice pointing towards a sort of amplification of the energy through a collective behaviour of the lattice.

Furthermore the work of Alfred Cöhn on electrodiffusion of hydrogen in the Pd lattice (Cöhn, 1929) has shown that hydrogen was present as protons in the lattice (deuterium had not yet been discovered at the time of Cöhn's investigations). This fact poses severe problems to the condensed matter theoreticians since it requires a very high energy for the formation of ionic hydrogen in the lattice. A possible

Born-Haber cycle (Fleischmann et al., 1994) based on dissolution of H^+ requires an energy as high as about 30 eV (i.e. $H_2 \rightarrow 2H$ requires 4.48 eV and $2H \rightarrow 2H^+ + 2e$ requires 27.2 eV).

Also the knowledge of the very early literature on the subject of fusion, e.g. see the paper from Oliphant et al. (1934), pointed towards the possibility of a different scenario for nuclear reactions in condensed matter. The importance of this paper lies in the fact that it led to investigations of the fusion process $D + D \rightarrow T + H^+$ in a Wilson cloud chamber (Dee, 1934). A surprising feature of these measurements was the observation of a significant number of tracks angled at 180° (whereas the track should have been angled at 160° under the experimental conditions); this could only be explained by the fusion of species which had lost most of their energy in the target!

In such a framework, the Fleischmann and Pons claim looks as a very intriguing scientific proposal even though the question posed in the context of Quantum Mechanics clearly shows that "Cold Fusion" should not be possible. The nuclear physics of deuterons in a lattice (with a space-time scale some six orders of magnitude smaller than the space-time scales of the lattice) should not differ from the nuclear physics in a vacuum (the principle of Asymptotic Freedom). Even if we are able to find in condensed matter quantum electrodynamics, a mechanism able to justify weak interactions such as the capture of "heavy" electrons by proton as suggested recently by A. Widom (Widom & Larsen, 2005), it is still hard to imagine a mechanism, different from a coherent electromagnetic field, able to dissipate the energy produced locally. So, Low Energy Nuclear Reactions cannot be a localized event but imply the revision of some of our implicitly assumed facts about condensed matter.

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From Cold Fusion to Condensed Matter Nuclear Science: 20 Years of Research

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Introduction: After 20 years of continuous study and tens of millions of research dollars spent worldwide it is appropriate to examine the basis for, and confidence in, what has been learned since the public announcements of a new effect in March 1989. One fact that seems irrefutable is the existence of a heat effect in the electrolytic deuterium-palladium system that is quantitatively consistent with nuclear, but not chemical heat production. Now established as the Fleischmann-Pons Effect (FPE) several tasks require further study:

1. Certain identification of the pathway from reactant (presumed to be D) to primary product (observed in some experiments to be ^{4}He),
2. Quantitative or upper bound definition of the products of secondary or tertiary reactions (the so-called ash),
3. Complete development of a mechanistic and quantitatively predictive physical and mathematical model for the reaction process,
4. Evaluation of potential applications of any new phenomena.

Excess Heat: The FPE is defined as the production of nuclear level heat from the electrochemical stimulation of the heavy water–palladium system. This effect has been observed by hundreds of people in dozens of laboratories around the world, and published in hundreds of papers as recently reviewed (Hagelstein et al., 2004; Storms, 2007). In fact the very breadth of diversity in experiment and calorimeter choice has contributed to a perceived irreproducibility (although the primary cause of apparent irreproducibility is the lack of measurement and control of variables critical to the effect).

Four important understandings developed from intensive studies at SRI of deuterium loading and calorimetry:

1. Irreproducibility in FPE experiments can be fully or at least sufficiently explained in terms of the electrochemistry of loading D into Pd.
2. In the absence of a measure or knowledge of the D/Pd loading the experimenter has no basis to judge whether an experiment could or should have produced excess heat.
3. After basic precautions are taken the irreproducibility of loading and interfacial kinetics is not largely or even primarily controlled by the electrolyte or the electrochemistry, it is controlled by the bulk palladium metallurgy.
4. An empirical and near quantitative understanding of the measured magnitude of excess heat effects, and more particularly of the failure to achieve the FPE, can be obtained from measurements made of the controlling variables, and the failure to achieve critical threshold values.

Pathway Identification: The primary nuclear reaction pathway identified or hypothesized to be associated with excess heat results in the production of ^{4}He. The observation of this ^{4}He also appears to be solid and reproducible although experiment difficulties have reduced the number of successful ^{4}He observations far below the number of reliable excess heat results. Miles and Bush were the first to demonstrate semi-quantitative correlation between the rates of creation of ^{4}He and excess heat (Miles & Bush, 1992). That effect has now been observed in a number of laboratories around the world including SRI (Hagelstein et al., 2004).

It is worth noting that several imaginative alternative nuclear reaction schemes have been proposed that produce ^{4}He at approximately the 24 MeV Q value of dd fusion. Although product ^{4}He has been observed with this Q value, issues possibly associated with lattice retention almost always have resulted in measured values larger than 24 MeV. In addition, in no case has it been possible to perform a rigorous {D, ^{4}He} mass balance to identify the reactant as well as the product. Unless or until the FPE is used on an industrial scale to produce heat it will remain experimentally impossible to measure or even observe the tiny consumption of a very leaky gas (D_2).

Associated Products (Ash): Additional products have been claimed of secondary reactions such as those that produce ash[1] in chemical combustion. Primary amongst the produced “ash” is tritium. This isotope appears both

temporally and quantitatively uncorrelated with excess heat production, but is clearly created in a number of experiments. Considerable discussion of this can be found in the excellent review by Storms (2007).

Rather than being the dominant observable product (together with neutrons) in a putative dd fusion reaction, tritium is generally created at times when excess heat production is not observed and is not expected. On the rare occasions when heat and tritium production are observed in the same experiment at similar times, the tritium yield is 4 to 6 orders of magnitude less than that expected for a dd fusion heat effect.

Tritium is relatively easily observed. It is present at very low background levels in most laboratories, and can be unambiguously identified by three different commonly-employed methods: liquid scintillation in the liquid phase; direct beta observation in the gas using proportional counters or ionization chambers; mass spectrometric measurement of the rate of production of ^{3}He via ^{3}H decay. All three methods have been used in FPE studies, increasing the reliability and confidence in tritium observation. Other isotopic effects also have been reported and proposed; these will be briefly reviewed.

Mechanism and Theory: There is at present no accepted theoretical explanation for the effect although significant advances have been made (Hagelstein, 2008). Nuclear reactions in the rarified environment of high energy beams or plasmas are generally understood in terms of local energy and momentum conservation in an assumed closed system encompassing only the putative reaction volume. It is not clear to what extent such simple considerations will prove to apply to nuclear reactions in solid lattices or in any form of condensed matter where the putative reactants and products are not isolated from their environment but are integral parts of the extended coherent system, the wave structure of the lattice.

Potential Applications: Possible practical use of the FPE and related effects will be considered from the perspective that the excess heat in the FPE is real, large and of nuclear origin. This will require that reactants, reaction pathway, products and ash can be isolated and identified, and that a comprehensive, quantitative, fundamental mechanistic theory can be (or is being) developed with predictive capability sufficient to allow safe and controlled scale-up, before it will be practical to consider fully the possibilities of application.

Note

[1] Interdisciplinary fields can mutilate jargon beyond its recognized meaning in the original discipline. The term “nuclear ash,” originally generated as a “where’s the beef?” slogan by early critics of cold fusion, has come to mean the products of heat generating reactions (either observed or absent). In the chemical combustion of hydrocarbons (our primary experience of fire and chemical heating) the products of combustion are CO_2 and H_2O. Like helium, both are gases and neither are ash. The ashes of chemical combustion are the oxidation products of trace metal impurities and the residuum of already oxidized fuel inclusions.

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Overcoming the Coulomb Barrier and Related Effects through Resonant Electrodynamics and Quantum Mechanics in the Fleischmann-Pons Effect

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Introduction: "Overcoming the Coulomb Barrier" is widely viewed as the reason that the Fleischmann-Pons Effect (FPE) cannot be the result of a nuclear process. However, considerable confusion about whether or not this particular "barrier" is actually relevant exists since what happens in the FPE is so radically different than what takes place in conventional fusion. I argue that this barrier is actually quite artificial and that the FPE can be explained by understanding subtleties involving how reactions can occur through quantum mechanics (QM). In particular, I am suggesting that general ideas involving resonance can explain, through electrodynamics, many of the observations associated with the FPE. Thus, I argue that the real barrier for understanding how Cold Fusion reactions can take place, in the FPE, is not overcoming the "Coulomb Barrier" but involves understanding subtleties related to how reactions can occur, based on the known laws of QM. In the paper, details about how this can take place are explained. A particular mechanism involving resonant electromagnetic dynamics is discussed that is consistent with the conditions that are present in the experiments, with the known laws of physics, and the underlying ideas suggested by Giuliano Preparata.

Results and Discussion: As opposed to a situation in which, in order for nuclear fusion reactions to take place, the reacting particles *must collide* with such high velocity that they can be treated as if changes in their electromagnetic interaction (EMI) are important only very near the location of the reaction, when many charged particles are involved, the effects of EMI can cause time-dependent changes to become important far from the reaction. In fact, in what appears to

be the most relevant, conventional fusion reaction (d + d → ^{4}He + γ), evidence exists that supports this picture since to explain the relevant dynamics, the conventional Coulomb Barrier picture actually must be modified significantly (Chubb, 2007, 2008c) to include the time-dependence in the EMI that is necessary to account for the γ-ray and for the fact that far from the reaction, the incident deuterons (d's) must have positive Bose Exchange symmetry and have net, vanishing spin.

In the most conventional picture of the Coulomb Barrier in fusion, each d is treated as a point-particle that is forbidden from colliding with a second d classically because of the infinite forces that occur as a result of Coulomb repulsion. This picture explains why fusion is difficult to achieve, but it over-simplifies the situation becausee it does not include QM. In a more "realistic" picture, the "point-particle" protons and neutrons are replaced by "wave-like" structures that are allowed to "collide" (their wave functions are allowed to overlap each other), despite the fact that the classical expressions for the energy and force become infinite. Although this picture is "more realistic," it is approximate because it only applies when the d's have sufficiently high velocity. Schwinger recognized that most physicists were not appreciating this fact during ICCF-1 when he (Schwinger, 1990) presented a complete, "exact" QM mathematical relationship (based on the Lippmann-Schwinger equation), which is actually very well-known, for deriving the fusion rate. This fact has not been widely appreciated by individuals either in the conventional fusion or cold fusion communities:

$$\begin{aligned}\text{Rate of reaction} &= \frac{2\pi}{\hbar}\langle Initial|V\,\delta\left(H - E_{Initial}\right)V\,|Final\rangle \\ &= \frac{2\pi}{\hbar}\left(\sum\nolimits_f \langle Initial|V\,|Final\rangle\langle Final|V\,|Initial\rangle\,\delta\left(E_{Initial} - E_{Final}\right)\right),\end{aligned} \tag{1}$$

where $E_{Initial}$ and E_{Final}, respectively, are the energies of the initial and final states, V is the "change" in potential associated with *any* possible collision, H is the exact (many-body) Hamiltonian, and the summation includes all final states.

A generalization of the classical concept of a "collision" is introduced in Equation 1. In particular, collisions implicitly occur in the expression through "virtual," scattering processes in each term in the summation. Specifically, each of these terms involves a functional form, $\frac{2\pi}{\hbar}\langle Initial|V\,|Final\rangle\langle Final|V\,|Initial\rangle$ (which can involve any number of particles), that can be viewed as a form of "virtual power" (Chubb, 2008c). Each of these terms can become arbitrarily large or small and involves forms of collisions that can occur over any length and/or time scale. When the sum over final states conserves energy (which is required by the delta function in Equation 1), the process can take place. Time reversibility is broken because it is never possible to determine the change in potential, the initial state and the final state precisely. As I mentioned, Equation 1, in principle,

is exact. It can be used to define a prescription for modeling new and novel effects that is considerably richer than is possible in the Gamow tunneling theory of the fusion process. This theory assumes a single final state is involved, consisting of three nucleons, moving away from a third nucleon at high velocity, except in regions in the immediate vicinity of the collision, and that the essential dynamical changes in the potential energy (*V,* in Equation 1) involve the strong force, exclusively, as opposed to a huge number of virtual processes that can be present.

Implicitly in an approximately ordered solid, a form of "Galilean relativity" exists, associated with the fact that in the limit in which there are no collisions, it is impossible to tell whether or not the "ordered regions" in the solid are in motion or at rest. This can have especially interesting consequences when collisions are weak because their contributions in Equation 1 can be stifled as a result of periodic order. The associated effect is a specific example of a more general phenomenon: near-resonance and nearly-resonant collisions. This occurs when contributions from many virtual collision matrix elements (many values of $\langle Initial|V|Final\rangle$ in Equation 1) become very small in a particular region of space. In particular, perfect resonance occurs when energy is conserved and the contribution to the "flux" of the many-particle current, associated with each matrix element (defined by the surface integral of the total particle current matrix element, $\langle Initial|\vec{j}(r)|Final\rangle$, over the boundary of the region; Chubb, 2008c), from the interior portion of the integral vanishes. Since energy is conserved in Equation 1, in this kind of situation, the total contribution from collisions in the interior vanish (so in this region $\langle Initial|V|Final\rangle = 0$), and with respect to $\langle Initial|$ and $|Final\rangle$ the total Hamiltonian (*H* in Equation 1) can be viewed as being a self-adjoint (Hermitean) operator in this region.

Formally, as a consequence, perfect resonance can be used to justify the approximate boundary conditions associated with the single-particle, energy band theory, developed by Bloch, which is the basis of heat and charge transport in solids, with the understanding that the theory actually can be applied even in situations in which the crystal lattice that is used has finite extent, provided the energies of the various states that are used are all very close to each other in value. As I have pointed out elsewhere (Chubb, 2003, 2008, n.d.), the associated conditions are guaranteed to apply to the full many-body Hamiltonian when the initial and final states involve many particles, provided the energies of the states involve the ground state, and the lowest-lying excitations, which, by construction, are all required to be related to each other through rigid Galilean transformations, in which all of the "particles" are allowed to move at once, rigidly, without the separation between any particle and the remaining particles being altered. As a consequence, as opposed to justifying conventional band theory, using stationary, bound eigenstates of an approximate single-particle Hamiltonian, the theory can be viewed as a near-resonance limit, involving the full Hamiltonian, as it applies to a periodically ordered, finite lattice that is allowed to move rigidly within the interior of a solid, and the associated eigenstates are wave functions ("resonant

states") that preserve periodic order. Because, in fact, it is never possible to determine the boundary of a solid (Chubb, 2003, n.d.), formally, the associated picture can be viewed as a definition. This alternative perspective justifies, formally, the implications of an alternative model, in which an approximate "Fermi Golden" rule fusion rate calculation and the possibility of overcoming the "Coulomb Barrier" was inferred from an approximate eigenstate model involving a two-body d-d wave function, that possesses Bloch symmetry (similar to the comparable symmetry that occurs when non-interacting d's occupy ion band states; Chubb & Chubb, 2008) in both its dependence on its center-of-mass and relative d − d separation variables. In this model, the Fermi Golden rule is used to evaluate the fusion reaction rate, using initial and final states, that only change in regions (which are located at the interior boundaries of the ordered lattice) where nuclear overlap takes place, based on the assumption that in both the initial and final states, the same wave function applies in regions where overlap does not take place but as the separation variable either vanishes or its magnitude approaches the magnitude of a Bravais Lattice vector, overlap becomes possible by allowing the change in momentum to become infinite. When the d-concentration is sufficiently small, this assumed, asymptotic, energy-minimizing solution satisfies a resonant condition, while the Fermi Golden Rule rate expression occurs through nearly-resonant forms of collisions, associated with small (infinitesimal) perturbations, in the zero of energy of the electromagnetic potential, through Equation 1, in regions where nuclear overlap can occur, both in interior and external regions of the lattice. This initial calculation of fusion rate is justified only when the energy per unit cell is on the order of the smallest (optical) phonon energies (~20 meV) which means the lattice must have 23.8 MeV/0.02 eV ~ 10^9 unit cells. However, a considerably smaller value of the lattice is possible in the presence of very weak externally applied forces. In this case an alternative model, associated with near resonance, can take place, in which the zero of momentum adiabatically changes, without exciting the system. This can occur provided the effective virtual power associated with the process is sufficiently small. In particular, as a function of time, when an external field $\vec{E}$ is applied, nearly-resonant fluctuations in the center of mass momentum can take place that can increase in magnitude, with time. When the complete many-body expression is included (through Equation 1, based on a generalization of multiple scattering theory; Chubb, 2003, 2008, n.d.), as the available momentum builds up, virtual collisions can couple resonantly when the product of the force ($e\vec{E}$) on each d, associated with "a collision," with the time t that is involved (which, in one dimension, for example defines a particular momentum $p(t) = e\vec{E}\,t$) obeys a matching condition, in which the associated deBroglie wavelength $\lambda_{deBroglie}(= \dfrac{h}{p(t)} = \dfrac{N}{n}a$; h = Planck's constant, n = integer $\leq N$, $2N$ = number of lattice sites). In the many-body generalization (Chubb, 2003, n.d.), whenever this condition occurs once, it can occur $2N$ times. In the simplest limit, $N = n$, $2N\lambda_{deBroglie} = a$, and as $p(t)$ increases in time, $\lambda_{deBroglie}$ can approach nuclear dimension. The apparent

"simplicity" of this picture involves relating the microscopic physics to the semi-classical limit involving how light interacts with matter. Here, the underlying idea that coherent oscillations of charge that Giuliano Preparata suggested could be important, in the long-wave limit, in the associated interaction is absolutely correct. His observation about this is truly important.

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Field Assisted Electroplating

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Introduction: As part of a senior class project for Chemical Engineers at UCSD, experiments on field assisted electroplating were conducted for both copper and Pd/D electrodeposition. Copper electroplating, both in the absence and presence of either an electric or magnetic field, was tested prior to conducting Pd/D electrodeposition. For the purposes of this project, the copper electroplating served as a control study to interpret and gain a better understanding on the effect of an external field on electroplating. The Pd/D codeposition experiments were set up to be replications of the LENR experiments conducted by SPAWAR Systems Center San Diego in hopes of attaining similar results.

Experiments: In the copper electrodeposition experiments, the effects of the electrolyte composition, the electrolyte pH, and application of an external

field were examined to adjust the plating process, the electroplating efficiency, and the surface morphology of the deposit. The pH of the electrolyte solution was controlled to ensure that cupric ions were plentiful for optimal copper plating. The electrolyte solution was sparged with nitrogen gas to displace dissolved carbon dioxide and oxygen gases and prevent the formation of carbonates on the cathode. Using a range of pH from 0.5 to 3, plating efficiencies ranged from 90–95% and did not result in a dramatic correlation between pH and plating efficiency. When Cu is plated out onto a Ag cathode from a 0.5 M copper sulfate solution in the absence of an external field, the resulting metal deposit is smooth, Figure 1a. However, electroplating in a magnetic field resulted in a metal deposit that had a rougher surface with pits and valleys, Figure 1b. The Lorentz forces of the magnetic field were positioned tangentially to the electric field, and caused a gradient in the electrolyte concentration near the cathode. This gradient encourages fractals to grow on the surface of the deposit. No effect on the surface morphology of the Cu deposit was observed when electroplating was conducted in the presence of an external electric field (Dini, 1993).

In the Pd/D electrodeposition experiments, Pd was plated out onto an Ag cathode from a $PdCl_2$-LiCl-D_2O solution. The cathode was in contact with a CR-39 solid state nuclear track detector. When traversing a plastic material such as CR-39, charged particles create along their ionization track a region that is more sensitive to chemical etching than the rest of the bulk. During chemical etching, the ionization trail left by the charged particle in the detector is dissolved away and a track remains as permanent hole or pit which can be seen with the aid of an optical microscope. The size, depth of penetration, and shape of the track provides information about the mass, charge, energy and direction of motion of the particle that created it (Nikezic & Yu, 2004). The Pd/D codeposition experiments were conducted in the presence of both external electric and magnetic fields. At the end of the experiments, the CR-39 detectors were etched in 6.5 N NaOH at 70°C for 7 hr. Microscopic examination of the CR-39 detectors shows the presence of pits in both codeposition experiments (with electric and magnetic fields). These pits occurred in areas where the cathode had been in contact

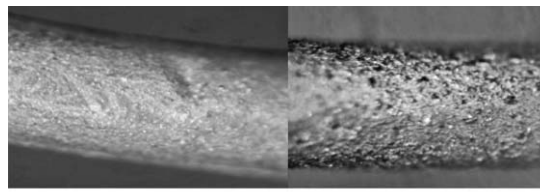

Fig. 1. Morphology of Cu electrodeposited from 0.5 M $CuSO_4$ in the (a) absence and (b) presence of an external magnetic field. The magnetic field within the cell is about 2500 Gauss.

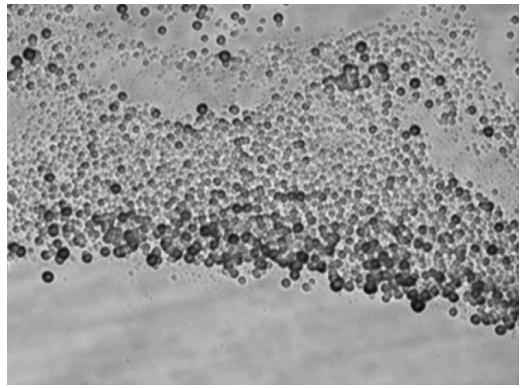

Fig. 2. ×200 magnification of a concentrated area of pits where the Ag/Pd cathode was in contact with the CR-39 detector during an external magnetic field experiment.

with the CR-39 detector. Figure 2 shows an image of the pits obtained at ×200 magnification. Several concentrated areas of dark pits are observed.

When focusing deeper inside these black pits, bright spots are observed that are due to the bottom tip of the conical track (Nikezic & Yu, 2004). The optical contrast, shape, and bright spot in the center of the pit are used to differentiate between real particle tracks (which tend to be dark) from false events (which are often lighter in appearance and irregular in shape) (Abdel-Moneim & Abdel-Naby, 2003; Ho et al., 2003). In Figure 3a mottled areas in the plastic are observed near the outer edges. The mottled areas show no contrast, and the shapes are irregular. These features are consistent with chemical damage. In Figure 3a, toward the center, more defined pits are visible. An arrow in Figure 3a indicates what appears to be a triple pit. Figure 3b shows an image of this triple pit at magnification ×1000. Possible explanations for the formation of a triple track are (i) that it is due to overlapping single tracks or (ii) it is the result of reactions that emit three particles of similar mass and energy. Focusing inside the triple pit to examine the bottom of the pit, Figure 3c, it appears that the individual lobes of the triple track are splitting apart. This favors explanation (ii) as the source of this triple pit. Such triple pits have been shown to form when CR-39 is bombarded with energetic neutrons (Abdel-Moneim & Abdel-Naby, 2003). The main constituent of CR-39 is ^{12}C (32% by weight). A neutron can briefly form a metastable ^{13}C then shatter into three alpha particles and the residuals of the reaction can be viewed in the CR-39 detector as a three-prong star similar to those shown in Figure 3b (Abdel-Moneim & Abdel-Naby, 2003). The deuterated water used in these experiments does contain tritium and there is prior evidence that tritium production in these cells does occur (Szpak & Mosier-Boss, 1998). One possible source of neutrons energetic enough to shatter carbon atoms is tritium-deuterium fusion.

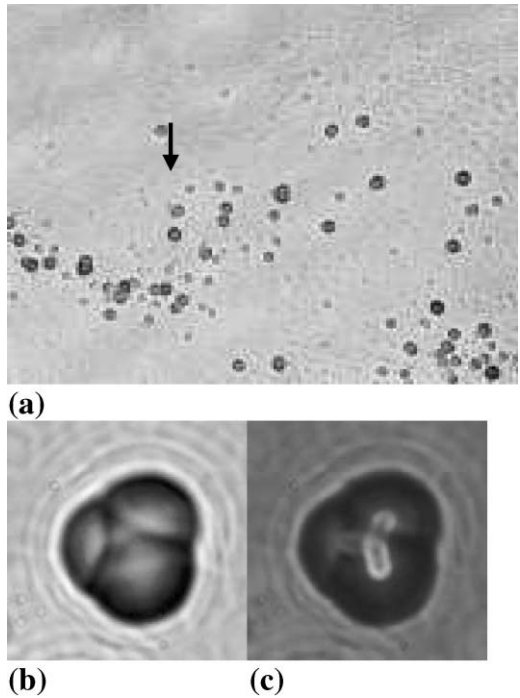

Fig. 3. (a) ×200 magnification of a cloudy area observed where the Ag/Pd cathode was in contact with the CR-39 detector during an external magnetic field experiment. Arrow indicates a "triple" pit. Images of the triple pit obtained at ×1000 magnification where (b) the focus is on the surface of the CR-39 detector and (c) the image is an overlay of two images taken at two different focal lengths (top and bottom of pit).

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From the Proof of Principle to the Working Prototype

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Twenty years of researches and hundreds of experiments on LENR brought to the shared opinion that it is indeed possible to produce nuclear reactions at low input energies.

The existence of an anomalous heat excess produced either during the electrolysis of heavy water with Pd cathode or during forced flux of deuterium gas through suitably structured materials has been reported by several experimentalists all over the world. Furthermore some guidelines seem to be shared among the scientists involved in these researches: (a) the existence of a threshold of deuterium loading in palladium is generally assumed as necessary (even if sometimes not sufficient) to trigger the phenomenon; (b) the mismatch between the measured yield of neutrons and tritium and the theory of nuclear fusion in vacuum; (c) the presence of ^{4}He as nuclear ash of the process; (d) the existence of other nuclear reactions, as transmutations of heavy elements, in condensed matter at room temperature; (e) the necessity of collective behavior in condensed matter in order to cope with this new phenomenology.

The next question is: "can such a phenomenon be envisaged, in the near future, as a new source of energy?" Most of the experimental efforts, in the past years, have been addressed to produce a "proof of principle" of the existence of LENR in condensed matter. It is still hard to say that the entire scientific community agrees to this claim, but there is no doubt that the whole subject cannot be discarded as a strangeness. Thus, it could be wise to start considering the problem.

The possibility to produce significant amount of energy from room temperature nuclear reactions may have at the present time such a paramount importance that a shared effort should be pursued from the scientific community.

In order to create a device able to produce significant amounts of energy for civilian uses, we have key problems still to be solved: (a) the reproducibility of the effect is not yet suitable for use by representative users or consumers, thus, there must be an effort in defining a special procedure able to drive the material over the trigger threshold without uncertainty; (b) the structural weakness of the cathodes and their inability to resist to several loading-deloading cycles needs the development of a material, maybe palladium or nickel based, suitable to be prepared in great quantities (hundreds of grams or more) and having a robust structure or a geometry with a high redundancy in order to face accidental ruptures; (c) the design of a "reactor" able to collect the most of the energy produced and to transfer it to an engine: the extremely high density power (1–10 KW/cm^3) evaluated by the experiments poses severe limits to the design of the device and we still need to know the maximum temperature reached by the materials and the performance a

regime; (d) the existence of nuclear reactions different from d+d producing other nuclear fragments and their potential applications.

In this presentation few types of new conception of cathodes will be discussed as possible examples. The experience we did with thin films cathodes (De Ninno et al., 2008) suggests that these structures are too much brittle for an industrial use, even though thin film technique allows solving some problems. Very small thicknesses reduce the Gorskij effect (De Ninno et al., 1997) (which is responsible for a force opposite to the H(D) uptake) during the loading; furthermore it is possible to apply an electric potential across the wire in order to induce the so called "Cöhn-Aharonov" effect without inducing high joule currents (Cola et al., 2000). However, the mechanic deformation induced by the loading itself (the Pd lattice expands up to 10% when it forms a hydride/deuteride) makes this system intrinsically fragile. One possible solution, still in the realm of the proofs of principle, can be the multiplication of the "basic" electrolytic cell in a more complex structure which allows to add both the energy and the 4He produced by the single cell in order to make easier their detection. In Figure 1 it is shown the comparison between an electrolytic cell model realized at ENEA-Frascati laboratories in the past and a device that sums the outputs of six separate cells.

A reasonable improvement aimed to have more material and to produce more energy should be represented by the use of thin wires, suitably woven as a cloth, in a single device. Another promising approach is represented by nanostructured Pd based materials. Several experimentalists have already shown (Arata & Zhang, 2003; Celani et al., 2008) the performance of these materials with respect to

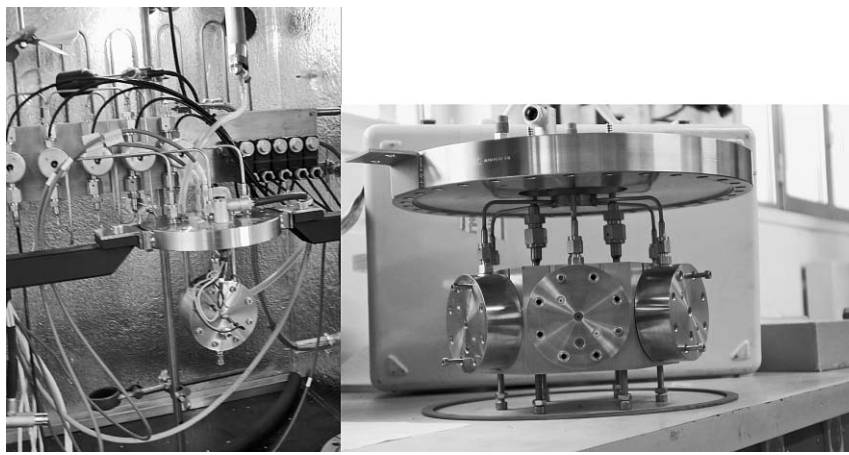

Fig. 1. (Left) Single electrolytic cell and its wiring inside the thermostatic box; (right) multiple cells device.

the loading, however a better chemical-physical characterization should be very important in order to exploit their capability (Marwan, 2008). A Pd or Ni nanostructured material may be used in electrolysis as "fluidised bed" as already proposed by M. Fleischmann (personal communication).

Another key issue is the possibility to have other nuclear reactions different from d+d → 4He in the lattice. The use of mass spectrometer specifically designed to analyse the gas produced by the electrolytic cells (Frattolillo et al., 2007), together with the use of more sophisticated techniques as SIMS (Secondary Ions Mass Spectroscopy) able to detect the elemental, isotopic, or molecular composition of a solid surface, should allow a very clear answer to this problem.

It is clear that, from an engineering point of view, we are just at the beginning of the challenge, but the peculiarity of this possible source of energy is important. In fact, we should be able to manage a very high density source of energy, very different from fossil fuels and also from the other known nuclear energy (fission, thermonuclear fusion) devices which require large-scale power plants. This means that its best use will be a non-centralized energy production, right at the site where it will be consumed, thus reducing the cost of energy losses in distribution and thermal wastes, i.e. the fact that a significant part of energy produced in a conventional plant subsequently reverts to waste heat into the environment.

The accomplishment of such an effort should require a skillful international supervision able to manage the work by different groups, even based in different parts of the world, selected on the basis of their competences.

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Dual Laser Stimulation of Optical Phonons in Palladium Deuteride

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Introduction: In work reported previously (Marwan & Krivit, 2008), two laser beams irradiating a deuterated palladium cathode at a single spot induced significant thermal increases many times larger than expected from laser heating alone. This effect was observed only when the lasers were tuned to produce a beat frequency near specific frequencies (around 8 THz, 15 THz and 20 THz). These preliminary experiments support the conjecture that optical phonons are involved in the heat producing mechanism.

In recent experiments, results from more than 20 runs appear to confirm the three thermally sensitive frequencies at 8, 15 and 20 THz. Further, the experiments allowed us to identify the approximate width of each heat-producing frequency and produce a crude thermal response spectrum (shown below in Figure 1).

Background: As is well known by now, on March 23, 1989 Fleischmann, Pons, and Hawkins first proposed the idea that nuclear reactions might be induced in deuterated palladium (Fleischmann et al., 1989). The idea was controversial from its inception, with its origins in experiment, in which the experimental results are inconsistent with established nuclear theory. The experiments of Fleischmann and Pons showed electrode power densities and figures of merit normally associated with nuclear reactions, but no indication of commensurate energetic particles. The claim for nuclear reactions induced in the solid state at room temperature rested mainly on the fact that known chemistry could not yield the observed power and energy densities. Experimental confirmations of their basic excess power result have been reported by many groups over the years (see, for example, Violante et al., 2005).

In 1993, Miles and Bush reported observations of ^{4}He correlated with the excess energy observed (Miles & Bush, 1993). The correlation between ^{4}He and excess energy is discussed in Hagelstein et al. (2004). More recent results were reported by Apicella et al. (2005) at ICCF-12.

There is now enough diverse experimental evidence to suggest that nuclear reactions really are possible in the solid state at room temperature. The appearance of ^{4}He in association with excess heat implicates reaction mechanisms in which two deuterons interact in some new way to produce ^{4}He, with the 24 MeV difference in mass energy somehow going into local degrees of freedom associated with the host lattice, rather than into energetic particles.

From the beginning, our third author pondered the role of phonons in the solid state fusion of deuterium. His early work proposed a coherent phonon-photon

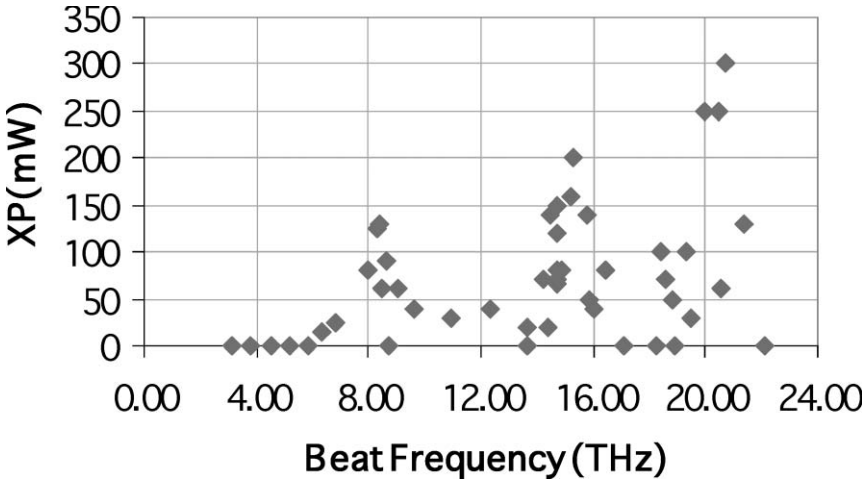

Fig. 1. A crude thermal response spectrum showing the three heat-producing frequencies for palladium deuteride.

mechanism as described in "Coherent Fusion Theory" as presented by Hagelstein (1989). Hagelstein proposed that the large nuclear energy release might be radiated into the lattice phonon field "one phonon at a time". By 2003, Hagelstein modified the details of his phonon theory based on a phonon exchange mechanism as reported in his ICCF-10 conference paper (Hagelstein, 2003); but the role of phonon coupling remained an important part of his overall theory. In his conjecture 4 in this paper, he states that "Anomalies in metal deuterides are stimulated by strong phonon excitation." In 2007 Hagelstein and coworkers refined the phonon theory further (Hagelstein et al., 2007); in this paper, idealized models for energy exchange between nuclear states and lattice vibrations are described, in which the 24 MeV quantum from the D+D $\rightarrow$ ^{4}He transition is transferred to the lattice coherently through a very large number of single phonon interactions. Optical phonon modes would have the advantage over acoustical phonon modes in that fewer single phonon exchange interactions are required. Of all the optical phonon modes, it would seem that those with the lowest group velocity are the most likely candidates. In palladium deuteride, the band edges (where the group velocity approaches zero) occur near 8 and 15–16 THz (see Glinka et al., 1978; Rowe et al., 1974).

Experimental Results and Discussion: The work discussed in this paper continues work that began in March 2007 as a series of experiments conducted by Letts and Cravens in collaboration with Hagelstein. Our goal was to see if an experimental connection could be made with the phonon aspects of Hagelstein's

model. Hagelstein's theory is complex but our experimental approach was simple—we used dual lasers in beat mode to create beat frequencies near the three known optical phonon modes for palladium deuteride. We had data for palladium hydride but guessed that the deuteride phonon modes would be similar. Before the first experiments were run, Hagelstein predicted that the edges of the optical phonon band would be the best candidates for stimulation to produce excess power. This region is where low group-velocity compressional phonon modes exist. This is consistent with our observations near 8 and 15 THz; but the response near 20 THz required an alternate explanation.

Perhaps the simplest conjecture for this higher frequency response is proton contamination, which might be expected to produce a zero-group velocity band edge near 20 THz. A new series of experiments was started in October 2008 to test this conjecture. In this new series of experiments, distilled light water was added in very small incremental amounts to the LIOD electrolyte while stimulating the cathode at 20 THz. At first there was no thermal response to the 20 THz stimulation but after adding 0.25 mL of H_2O to the 100 mL of electrolyte a small heat response was observed. This response was encouraging, but not sufficient to qualify as an explanation for the 20 THz effect. Additional experiments will be conducted to test the effect of H_2O contamination on the 20 THz signal.

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Composition of Particles in Heavy Water Electrolyte after Electrolysis

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Introduction: Using a scanning electron microscope (SEM) equipped with an energy dispersive spectrometer (EDS), it was shown previously that changes in topography and chemical composition occurred on the surface of a Pd cathode which had been electrolyzed in heavy water electrolyte and then stored at ambient temperature and pressure (Dash et al., 1997). Figure 1a shows microtubes on the surface of the Pd cathode about 6 months after electrolysis. Two days later significant changes in topography had occurred, Figure 1b. One of the new features is indicated by the arrow labeled E1. A portion of an EDS spectrum from this particle (Figure 1d) is shown to the right of Figure 1b. The peaks identified in this spectrum are for AgLα1 at about 3 keV and AgLβ1 at about 3.15 keV. The expected peak intensity ratio, AgLβ1/AgLα1, is 0.42, but the actual ratio in Figure 1d is 0.57. About 2 months later, significant changes were observed, both in the topography and in the characteristic x-ray ratio, Figure 1c and e. Here we report time-dependent changes in topography and microcomposition of particles collected from the electrolyte surfaces after electrolysis.

Experimental Methods: Recently, we have observed particles floating on the surfaces of electrolytes after electrolysis, in four cells, each of which contained a heavy water electrolyte and a Pd cathode. Solid particles were unexpected from electrolysis, so it seemed important to characterize these particles. Cu grids were used to collect particles from the electrolyte surface. Then the SEM and EDS were used to study the surfaces of these particles and to record time-dependent changes which were occurring.

Results and Discussion: Pons and Fleischmann described a phenomenon called "Heat after Death", in which an electrolytic cell with heavy water electrolyte and a Pd or Pd alloy cathode remains at high temperature for a few hours after electrolysis stops (Pons & Fleischmann, 1994). No data about surface topography or chemical composition of the cathodes was included in this report. Another study used a titanium disc gas loaded with deuterium (Srinivasan, n.d.). Autoradiography was used to record emissions from the disc. The disc was checked by autoradiography several times over a period of 1 year. The same pattern of film darkening was observed each time. We are not aware of any other studies of time-dependent changes of topography and composition of metals after interaction with hydrogen isotopes.

Figure 2 shows a group of particles attached to a Cu grid bar (vertical feature on the left).

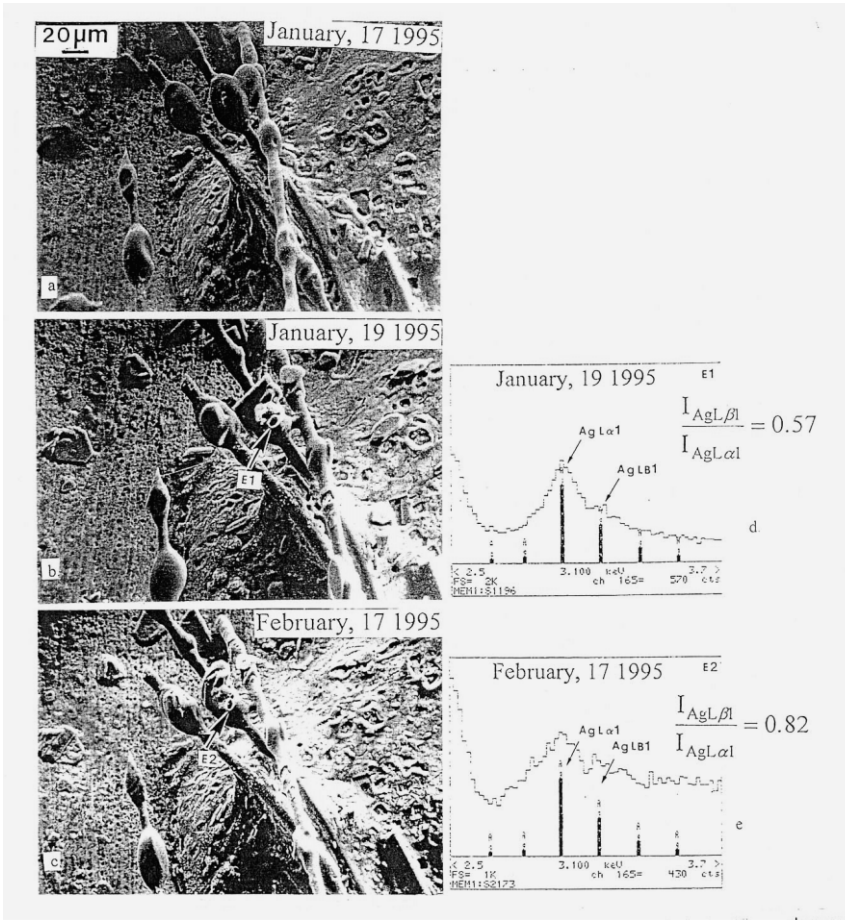

Fig. 1. (a–c) Changes in morphology of fibers which formed on a Pd cathode during electrolysis. These changes occurred during storage at room temperature. (d, e) EDS spectra showing changes in composition which were detected at spot E1 on January 19, 1995 and at spot E2 on February 17, 1995.

Semiquantitative EDS analysis of a 20 μm diameter microsphere showed that it contained about 50 at.% C and 50 at.% Pd. One day later the same microsphere was found to contain about 76 at.% C and 24 at.% Pd. The matrix near the microsphere contained about 25 at.% C, 70 at.% Pd, and 5 at.% Ag. A spectrum taken from the same place the next day showed that there was no significant change in composition. We do not have an explanation for the high carbon content of the microsphere or for its rapid change with time. The matrix near the microsphere also has much higher C content than is expected. High C content on the surface of a thin Pd cathode after electrolysis in a D_2O electrolyte was reported previously

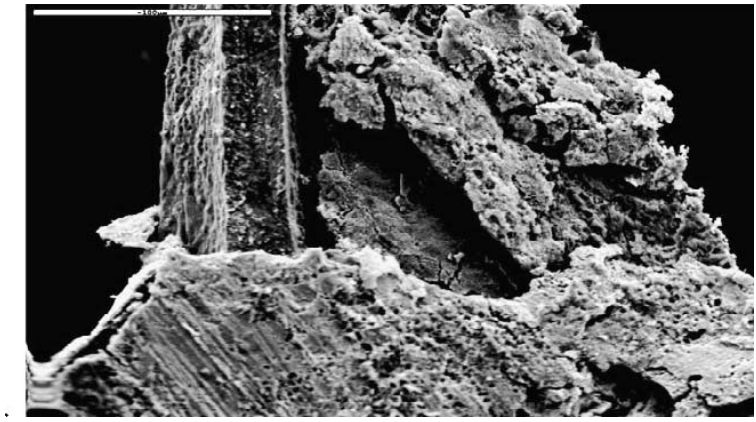

Fig. 2. Floating particles were collected from the electrolyte surface after electrolysis.

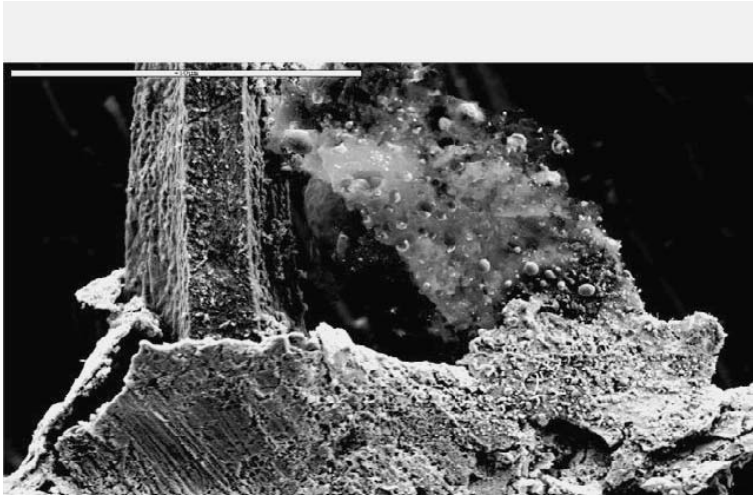

Fig. 3. The same particles as in Figure 2 after storage at ambient for 11 days. The spherical particles and the surrounding matrix in the upper right quadrant were analyzed using EDS.

by Chicea, who suggested that this might result from novel low energy nuclear reactions (Chicea, 2003).

The presence of appreciable Ag in the matrix near the microsphere may be the result of the absorption of thermal neutrons by Pd, thus forming an unstable isotope which beta decays to form Ag (Dash et al., 1994). This reaction is exothermic (about 1.1 MeV). In Figure 3, it appears that localized melting has occurred. This was followed by solidification, leaving a smooth region where the microspheres were formed, possibly from gases released from the molten Pd.

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Study of the Palladium Hydrogen–Deuterium System

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Introduction: It is obvious that cold fusion is not similar to thermonuclear hot fusion processes. An appreciable number of available documents report on different methods by which nuclear reaction is produced and controlled at low temperature (Fox, 1994). Those methods are ranging from the use of gun-powder technique to the attempt to electrochemically induce nuclear fusion and fission with large excess heat in a deuterium containing metal lattice (Bockris & Lin, 1992; Fleischmann & Pons, 1989; Mosier-Boss et al., 2002). The emphasis is directed towards the fabrication of so called "cold fusion devices" with unique commercial potentials demonstrating the power of low-temperature nuclear reactions as one of the alternatives to the use of fossil fuels. The idea of cold nuclear fusion has led to endless discussions about the kinetic impossibility of intense nuclear reactions with high coulomb barrier potentials. During the memorable Pons-Fleischmann experiment in 1989 (Fleischmann & Pons, 1989), involving electrochemical cells using heavy water with the corresponding electrolyte in the solution and palladium as the electrode, significant excess heat was discovered, challenging all current atomic models (Miles et al., 1990). The attention has been focused to the development of new ideas ranging from nucleon-cluster to the electron charge–cluster model (Fox, 1994). Reproducibility of cold fusion reactions has been hardly obtained, and no research group has fully resolved the problems associated with the special preparation of the metal electrode, the loading of heavy water and the turning on of excess heat.

This paper highlights the research on the nanostructured palladium hydride system outlining the kinetic behaviour of hydrogen and deuterium diffusing into the pores of the nanostructure. To our understanding, this kinetic aspect is

believed to be the key issue to achieve nuclear reactions within metals of any choice (Marwan, 2005).

Materials and Methods: Hydrochloric acid (AnalaR BDH), sulphuric acid (AnalaR BDH), ammonium tetrachloropalladate (premion-99.998% Alfa Aesar), hydrogen hexachloroplatinate (IV) hydrate (99.9% Aldrich), Brij56® (Aldrich), crystal violet (Aldrich), octaethyleneglycol monohexadecyl ether ($C_{16}EO_8$, Fluka), and heptane (99%, Lancaster) were all used as received. All aqueous solutions were freshly prepared using reagent-grade water (18 MΩ cm) from a Whatman "Stillplus" system coupled to a Whatman RO 50. All glassware was soaked overnight in a 3% Decon/deionized water solution and washed thoroughly at least three times with deionized water prior to use.

All electrochemical experiments were carried out using an EG&G Model 263A potentiostat/galvanostat with a large area platinum gauze counter electrode and either a homemade saturated mercury sulfate (SMSE) or saturated calomel electrode (SCE) reference electrode. The counter electrode was a large area platinum gauze. The SMSE was used to avoid chloride contamination of the sulphuric acid electrolyte solution used in the studies of the nanostructured metal electrodes and all potentials are reported with respect to this reference electrode (potentials with respect to SMSE are shifted 0.45 V negatively of the corresponding potential vs. SCE). The reference electrode was used in conjunction with a luggin capillary and stored in a saturated potassium sulfate solution when not in use.

The H_1-e Pd films were freshly prepared before each electrochemical experiment by electrochemical deposition on to gold disc electrodes (area 0.0079 m^2) formed by sealing 1 ± 0.1 mm diameter gold wire in glass. Immediately before use, the gold disc electrodes were freshly polished using silicon carbide paper (Cc 1200, English Abrasives) and then alumina/water slurries (Buehler) starting with a particle size of 25 μm and ending with a particle size of 0.3 μm. H_1-e Pd films were deposited from a solution containing 12 wt% $(NH_4)PdCl_4$, 47 wt% $C_{16}EO_8$ or Brij56®, 39 wt% water and 2 wt% heptane at 25°C. These conditions correspond to the hexagonal (H_1) lyotropic phase for both mixtures as determined by studies of the phase diagram for the system. These deposition mixtures are highly viscous and must be prepared with care to ensure a uniform composition. After all of the components were mixed, the mixture was heated and stirred to ensure homogeneity and then cooled before use. Pd was deposited from the liquid crystalline plating mixture at 0.1 V. After deposition the H_1-e metal films were rinsed in purified water to remove the adherent surfactant mixture.

Electrochemical measurements on the H_1-e Pd films were carried out at room temperature (18–23°C) in 1 M H_2SO_4. Before each experiment the solution was sparged for 10–15 min with a stream of highly purified argon gas to displace dissolved oxygen. The electrochemical active surface areas of the H_1-e Pd films were estimated by integrating the charge passed in the surface oxide stripping reaction recorded in 1 M sulphuric acid following the procedure suggested by Rand and

Woods (1972). Small amounts of Pt were deposited onto the H_1-e Pd surface from an aqueous solution containing 25 mM H_2PtCl_6 and 1 M HCl. The surface coverages were calculated from the charge passed to deposit the Pt and the surface areas of the H_1-e Pd films determined from the voltammetry.

Results and Discussion: Electrochemical deposition of metals from hexagonal lyotropic liquid crystalline phases produces metal films with a unique ordered nanostructure in which the cylindrical pores of 1.7 to 3.5 nm running through the film are arranged in hexagonal arrays (Attard et al., 1997a,b, 1998). Nanostructured Pd films were deposited electrochemically from the template mixture of either $C_{16}EO_8$ or Brij®56. Electrochemical studies showed that the metal films have a high electroactive surface area with the specific surface area of the order of 91 m^2/g. These values together with the TEM and X-ray data are consistent with the expected H_1 nanostructure (Bartlett et al., 2002). The hydrogen region of

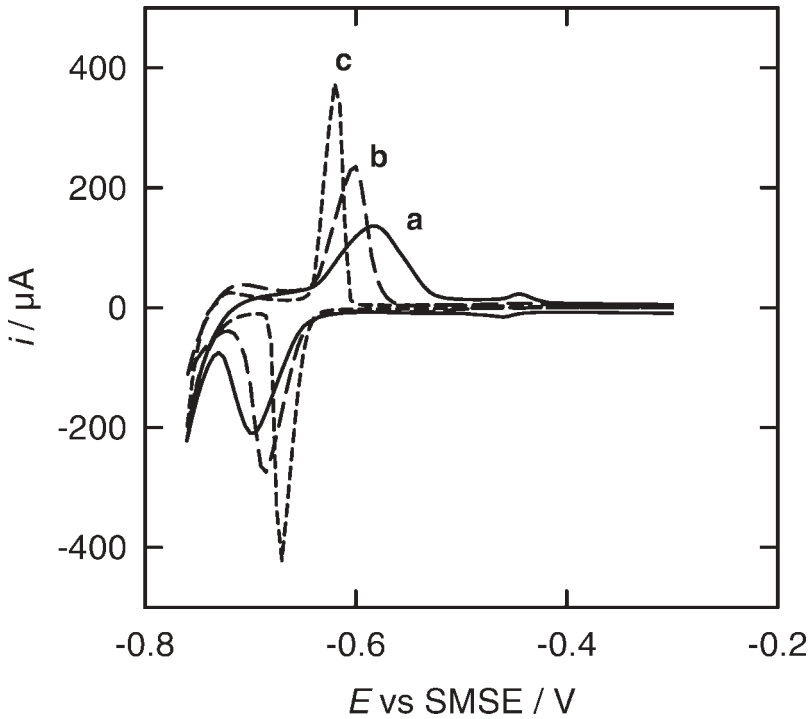

Fig. 1. Set of cyclic voltammograms of H_1-e Pd (200 nm thick, deposition charge 3.5 mC, deposited from the Brij®56 plating bath) deposited on a gold disc electrode (area 0.0079 cm^2) recorded at 10 mV/s in 1 M H_2SO_4 (a) without crystal violet, (b) in the presence of 0.5 mM, and (c) 1 mM crystal violet.

nanostructured Pd in the cyclic voltammetry in 1 M H_2SO_4 was more resolved than that of plain Pd because of the thin walls of the nanostructure and the high surface area. We could distinguish the hydrogen adsorption and absorption processes. The permeation of hydrogen into the Pd metal lattice occurs with fast kinetics when the Pd surface is blocked by either crystal violet or Pt. We believe that the hydrogen absorption process takes place without passing through the adsorbed state so that hydrogen diffuses directly into the Pd bulk. This process speeds up when the formation of adsorbed hydrogen is suppressed by the coverage of poisons (Bartlett & Marwan, 2004) (Figure 1). These results were compared to those obtained in a heavy water solution to which the Pd electrode was exposed. Adsorption characteristics of deuterium on the Pd metal surface are slightly different to those obtained for hydrogen in previous studies. Diffusion of deuterium into the Pd metal lattice works with fast kinetics under appropriate surface modification.

In this paper we attempt to propose a consistent model describing the cold fusion phenomenon (Marwan, 2007). We expect this model to contradict the recent scientific philosophy regarding nuclear fusion processes. To our mind, cold fusion is a natural, permanently ongoing process.

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Twenty-Year Review of Isoperibolic Calorimetric Measurements of the Fleischmann-Pons Effect

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Introduction—Why Choose a Dewar Isoperibolic Calorimeter?: The Dewar type of isoperibolic calorimeters developed by Fleischmann and Pons provides a wide dynamic range for both the cell temperature and cell input power. The experimental temperature range can be as great as the liquid range of the electrolyte system (3.82°C to 101.42°C for pure D_2O). For typical D_2O + 0.1 M LiOD electrolytes, the temperature range used is typically from 20°C dictated by the bath temperature up to the boiling point of the electrolyte. The maximum cell input power will vary with the size of the cell, but input powers up to 10 W are possible before the cell contents are driven to boiling temperatures.

The ability provided by the Dewar type cells for directly observing processes inside the cell is a very important advantage. This is especially important for co-deposition and cell boil-off experiments. Other calorimetric systems generally do not provide for visual observations inside the cell.

The relatively low cost of the Dewar type cells is another important factor for the selection of this isoperibolic system. This makes possible the simultaneous use of multiple cells involving different experiments in a single water bath of sufficient size for handling the total heat output. The major cost is simply the construction of glass Dewar cells with a high vacuum between the inner and outer glass surfaces. The top portion (about 30%) needs to be silvered to minimize the effect of the decreasing electrolyte level caused by the electrolysis of D_2O to produce D_2 and O_2 gases. Larger cells will obviously exhibit smaller changes in the electrolyte level during electrolysis.

Another important positive feature of these Dewar cells, as well as other open systems, is that they are self-purifying. Ordinary H_2O will act as a poison to the Fleischmann-Pons (F-P) effect in D_2O + 0.1 M LiOD electrolytes. Because H is preferentially electrolyzed versus D at the cathode, any H_2O contamination will be gradually removed during electrolysis. In closed systems, the initial H_2O contamination will remain trapped throughout the experiment. Not to be overlooked is the inherent safety of an open system that allows the deuterium and oxygen gases to escape as fast as they are generated.

The main heat transfer pathway for Dewar isoperibolic cells is via electromagnetic radiation (mostly infrared radiation). The radiative heat transfer coefficient, therefore, can be estimated by using the Stefan-Boltzmann constant and the experimental surface area of the inner, unsilvered portion of the glass surface of the Dewar cell. This provides a useful guide to the integrity of the Dewar vacuum

and the extent of minimization of heat transfer pathways via conduction. Because of the predominate heat transfer by electromagnetic radiation, this Dewar cell system has no memory effect. For example, gas bubbles or stagnant layers that form on the inner cell wall will exert no effect on the radiative heat transfer coefficient. Any media in the cell will suffice that maintains the temperature of the inner cell wall.

The F-P Dewar System: The F-P isoperibolic calorimetry using a Dewar type cell evolved through various designs dating back to the early 1980's. The major changes involved the dimensions selected for the cell as well as incorporating the silvering of the top portion of the cell (Fleischmann & Miles, 2006; Miles & Fleischmann, 2008). Proper scaling of the system is critical because the cell diameter and length determine the volume of electrolyte used, the rate of change of the electrolyte level, the effectiveness of stirring by the electrolysis gases, the dynamic range for power input, and the magnitude of the calorimetric constants. These changes led to the Isoperibolic Calorimetry: Acquisition, Research and Utilities System (ICARUS) series of cells used in later experiments.

The ICARUS 1 to 3 calorimeters were for lower temperatures up to boiling, and the ICARUS 4 to 9 calorimeters allowed long-term maintenance of boiling conditions. Results of ICARUS 9 experiments have been presented (Roulette et al., 1996). The ICARUS 10 to 13 were designed and constructed for further studies of boiling, but they were never put in use (Miles et al., 2001). A schematic diagram for the ICARUS-14 calorimeter is available, but this calorimeter was never constructed (Miles et al., 2001). An example of the ICARUS-1 type cell used at the New Hydrogen Energy laboratory at Sapporo, Japan from 1994 to 1998 had a filled electrolyte volume of 90 cm^3, an inner diameter of 2.5 cm, an outer diameter of 4.2 cm, and a length of 25.0 cm with the top 8.0 cm silvered. A similar F-P Dewar cell was used in France by Lonchampt and Bonnetain (Lonchampt et al., 1996).

The modeling and mathematical equation of the F-P Dewar isoperibolic calorimeter have been previously presented (Fleischmann, 2002; Fleischmann & Miles, 2006; Miles & Fleischmann, 2008; Miles et al., 2001; Szpak et al., 2002). A detailed version of this present paper containing all the equations is available electronically (Miles & Fleischmann, n.d.). The correct equations for modeling isoperibolic calorimetry using open cells are now well established and can give highly accurate results (Miles & Fleischmann, 2008, n.d.). There has been no challenge to these calorimetric equations in any refereed scientific publication even after nearly 20 years. Therefore any institution that performs accurate isoperibolic calorimetry using open cells must correctly account for all of the following power terms:

1. Power for the calorimetric system itself due to changes in the cell temperature.
2. Electrical power due to the electrochemical reactions.
3. Power due to the transfer of heat by electromagnetic radiation.

4. Power due to the transfer of heat by conduction.
5. Power carried out of the open system by the gases exiting the cell including D_2O vapor.
6. Power applied to any internal heater.
7. Power due to the rate of any pressure-volume work done by the electrogenerated gases.
8. Power due to any anomalous source (Excess Power).

Isoperibolic calorimetric measurement in 1989 at three influential institutions prematurely squashed the public and scientific considerations of the F-P effect. These three institutions (California Institute of Technology [Caltech], Massachusetts Institute of Technology [M.I.T.], and Harwell) did not account for many of the power terms listed above.

Caltech Calorimetry: The initial publication by Caltech on the F-P effect was received by *Nature* on 23 May 1989 (Lewis et al., 1989). This means that all work was completed in less than 2 months after the initial announcement of the F-P effect (March 23, 1989). It is remarkable that Caltech claimed completion of multiple calorimetric experiments in this short time span because completion of a single F-P experiment generally requires 4 to 8 weeks or more of electrolysis.

The first step in evaluating this Caltech calorimetry is to look for the required power terms in the modeling equations. The Caltech paper is almost devoid of equations for these power terms. Only terms for the electrochemical power and an expression for the total power could be identified (Miles & Fleischmann, n.d.). The Caltech calorimetric cell consisted simply of a Dewar flask containing 30 mL of electrolyte, but the Dewar walls contained 1 atm of air, hence there was no vacuum and heat conduction would dominate over electromagnetic radiation. The most disturbing aspect of the Caltech report concerns the heating coefficient that was allowed to change with time to give zero excess power. This heating coefficient should have a nearly constant value as found in their control study using ordinary water. The Caltech heavy water experiment is more correctly interpreted as an excess power effect (Miles & Fleischmann, n.d.).

M.I.T. Calorimetry: The two M.I.T. calorimeters used glass wool thermal insulation in the compartment between the cell and water bath (Albagli et al., 1990), thus their main heat transfer pathway was by conduction rather than by electromagnetic radiation as in the F-P Dewar cells. The sensitivity of the Phase II M.I.T. calorimeters was stated as ±40 mW (Albagli et al., 1990) contrasted to ±0.1 mW sensitivity for the F-P Dewar calorimeters (Fleischmann & Miles, 2006; Miles & Fleischmann, 2008). From the dimensions of the M.I.T. Pd rod cathodes (0.1 × 9 cm), the expected excess power of about 70 mW would not easily be distinguished from the large calorimetric error reported. The M.I.T. laboratory reported their key calorimetric measurements over a rather short time period (100 hours). The observation of excess power with Pd cathodes in heavy water generally requires 6 days or more of electrolysis.

To M.I.T.'s credit, most of the required power terms were considered in their analysis. The main problem with the M.I.T. experiments is that there is a serious discrepancy between the unpublished raw data showing a small excess power effect and the final published data for their heavy water cell (Miles & Fleischmann, n.d.). The data points appear to have been arbitrarily shifted down to make the excess power vanish (Miles & Fleischmann, n.d.). Because a "wake" to ridicule cold fusion at M.I.T. was already planned before the experiments were completed, it would have required unusual honesty for M.I.T. to have correctly reported a small excess power effect.

The Harwell Calorimetry: The Harwell (U.K.) laboratory investigated the F-P effect using Dewar calorimetric cells during the early stage (1989) of the cold fusion controversy (Williams et al., 1989). These Harwell experiments were hastily performed, and the reported calorimetric error of ±15% falls far short of the ±0.01% error reported by Fleischmann (Fleischmann & Miles, 2006; Miles & Fleischmann, 2008). The Harwell publication (Williams et al., 1989) provides only fragmental information about the power terms and equations used in their calculations for their Dewar cell. Most of the required power terms are missing in their analysis of the data (Miles & Fleischmann, n.d.). To the credit of the Harwell group, their raw experimental data was made available to other groups. Several independent analyses of this raw data have reported that excess enthalpy generation was in fact observed in the Harwell study contrary to the conclusions reached by the authors (Miles & Fleischmann, n.d.).

Summary: The correct equations for modeling isoperibolic calorimetry using open cells are now well established and can give highly accurate results. These calorimetric equations were used to evaluate the Caltech, M.I.T., and Harwell calorimetry performed in 1989. It appears that scientific objectivity was sacrificed by these three influential institutions in order to obtain their desired result of no anomalous excess power effects.

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Characterization of Neutrons Emitted during Pd/D Co-Deposition

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Introduction: In the inertial confinement fusion (ICF) field, CR-39 is a solid state nuclear track detector used to detect energetic particles such as alphas, protons, deuterons, and tritons as well as neutrons. Because CR-39 is an allyl glycol carbonate plastic, it is not affected by the electromagnetic pulse that disables electronic detectors in ICF experiments. When energetic charged particles travel into or through a CR-39 detector, they create along their ionization track a region that is more sensitive to chemical etching than the rest of the bulk. After treatment with an etching agent, tracks remain as holes or pits whose size and shape can be measured. The attributes that make CR-39 the detector of choice for ICF measurements also make it an ideal detector for detecting particle emissions in the Pd/D system. Also, since CR-39 detectors are examples of constantly integrating detectors, events are permanently stamped on the detector. This is

particularly important for systems, like Pd/D, that exhibit low flux rates and/or events that occur in bursts.

In the Pd/D co-deposition experiments, the cathode is in direct contact with the CR-39 detector. Tracks have been observed on both the front and back surfaces of the CR-39 detectors. The primary DD reactions and secondary DT and D^3He are:

$$D + D \rightarrow T(1.01\ MeV) + p(3.02\ MeV)$$
$$D + D \rightarrow n(2.45\ MeV) + {}^3He(0.82\ MeV)$$
$$D + T\ (\leq 1.01\ MeV) \rightarrow \alpha(6.7 - 1.4\ MeV) + n(11.9 - 17.2\ MeV)$$
$$D + {}^3He\ (\leq 0.82\ MeV) \rightarrow \alpha(6.6 - 1.7\ MeV) + p(12.6 - 17.5\ MeV)$$

If these reactions are occurring, the protons, alphas, tritons, and ^3He formed in the primary reactions and the alphas formed in the secondary reactions will leave tracks on the front surface of the CR-39 detector. The neutrons formed as the result of the primary and secondary reactions will undergo elastic interactions with CR-39 and will leave latent recoil charged particle tracks on the front surface of the detector as well (Phillips et al., 2006). The size of the pit created in the CR-39 detectors depends upon the mass, energy, and charge of the particle that created the pit. Under ideal conditions, it would be possible to differentiate the particles based upon an analysis of the size of the tracks. However, in reality, the particles exhibit a size distribution due to scattering and the presence of water in the Pd/D co-deposition experiments will slow the particles down. All of these factors make speciation of the tracks on the front surface of the CR-39 detectors impossible. The only species that can contribute to the tracks on the backside of the CR-39 detectors are neutrons and the protons resulting from the D^3He secondary reaction. The protons will leave very small holes on the backside of the CR-39 (< 1 μm in diameter) and can be readily differentiated from the tracks (≥ 5 μm in diameter) (Phillips et al., 2006) due to the neutron elastic and inelastic interactions with the CR-39 detectors. There are a number of potential uses for neutrons. They could be used to create energy by 'burning' ^{238}U. They could also be used to remediate radioactive waste and to create radionucleotides used in medical procedures. However, in order to determine what uses can be made of these neutrons, their energies and numbers need to be known.

Results and Discussion: The possible interactions of DD neutrons (2.45 MeV) and DT neutrons (14.1 MeV) are described in Figure 1a. In the interaction shown in case 1, the DD and DT neutrons can scatter elastically, producing recoil protons, carbons, or oxygen nuclei in the forward direction. But DT neutrons can also undergo two inelastic, (n,p) and (n,α), reactions with carbon or oxygen: case 2 and case 3, respectively, in Figure 1a. These inelastic reactions result in charged particles that can produce tracks on the front and/or the back side of the CR-39 detector. Phillips et al. (2006) have shown that neutron spectrometry can be done using CR-39. At low neutron energies (0.144 MeV), only recoil protons are seen and are observed as a peak at ~10 μm neutron. As the neutron

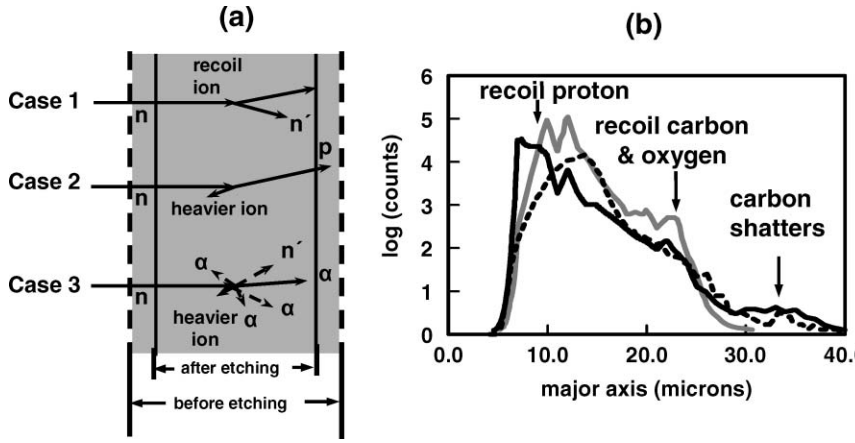

Fig. 1. (a) Schematic drawing of the CR-39 track detector and the neutron interaction processes that can take place inside the plastic (Frenje et al., 2002). The drawing is not to scale. Case 1 summarizes the DD neutron interaction with CR-39. Cases 1–3 describe the DT neutron interactions with CR-39. (b) Comparison of track size distribution obtained on the back side of a CR-39 detector used in Pd/D co-deposition (dashed line) with CR-39 detectors that have been exposed to 2.45 (gray line) and 14.8 (black line) MeV neutrons (Phillips et al., 2006).

energy increases, a broadening of the proton recoil peak at ~10 μm is observed. At 1.2 MeV neutron energy, a second peak is visible at ~25 μm. This second peak is attributed to recoil carbon and oxygen atoms. For neutron energies between 1.2 and 8 MeV, the size distributions of tracks observed in the CR-39 detectors are roughly similar. In the CR-39 detector exposed to 14.8 MeV neutrons, a decrease in the proton recoil at ~10 μm is observed and a peak is observed at ~35 μm which is attributed to the three alpha particle reactions. Figure 1b shows the size distribution obtained for neutrons whose energies are 2.45 and 14.8 MeV. The peaks due to recoil protons, recoil carbon and oxygen, and carbon shattering are indicated. This figure shows that DD and DT neutrons can be differentiated. Compared to DT fusion, the recoil proton peak observed for DD fusion is shifted to larger track size. The shift to larger track size is probably due to the fact that the DD neutrons are less energetic than the DT neutrons. The energy transferred to a proton is less when hit by a DD neutron than with a DT neutron. Less energy results in bigger tracks. For DT fusion, a peak is observed between 30 and 40 microns that is attributable to the carbon breakup reaction. This peak is absent in the DD fusion track size distribution. Figure 1b also shows the size distribution obtained on the back side of a CR-39 detector that had been used in a Pd/D co-deposition experiment. The Pd/D co-deposition size distribution exhibits features consistent with both DD and DT fusion. Given the efficiency of CR-39 for neutrons (10^4 to 10^5 neutrons/track), the number of neutrons generated during a 2 week long co-deposition experiment is estimated to be 10^8 to 10^9 neutrons.

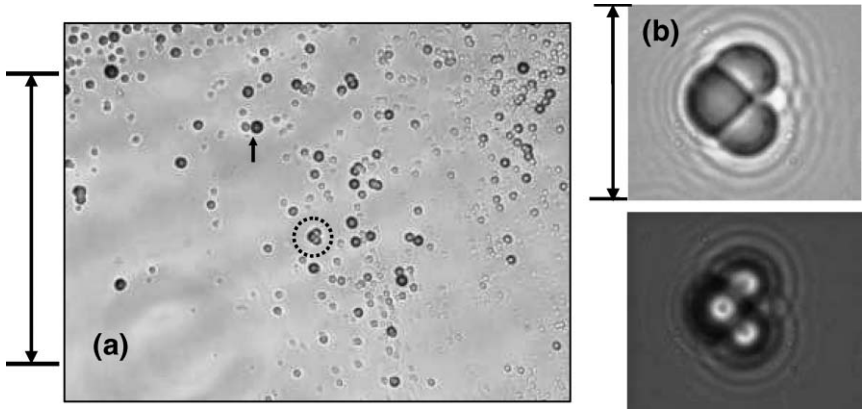

Fig. 2. (a) Image of a triple track (circled) among the solitary tracks (magnification ×200, scale is 250 μm). The CR-39 detector had been etched for 6 h in 6.5 M NaOH at 62°C. Arrow indicates a double track. (b) Image of the triple track shown in (a) at magnification ×1000 (scale is 25 μm). In the top image, the focus is on the surface of the CR-39 detector while the image on the bottom is an overlay of two images taken at two different focal lengths (surface and bottom of the pits).

Examination of the photomicrographs also provides evidence supporting DD and DT fusion. Figure 2a shows an image of tracks obtained on the front side of CR-39 as the result of a Pd-D co-deposition experiment. A triple track is observed interspersed among solitary tracks as well as double tracks. Possible explanations for the formation of a triple track are that (i) it is due to overlapping single tracks or (ii) it is the result of reactions that emit three particles of similar mass and energy. Figure 2b shows the triple track at higher magnification. Focusing inside the bottom of the triple track pit, Figure 2b bottom image, appears that the individual lobes of the triple track are splitting apart from a center point. This favors explanation (ii) as the source of these triple pits. The presence of three α-particle tracks outgoing from a single point is diagnostic of the $^{12}C(n,n')3\alpha$ carbon breakup reaction (Al-Najjar et al., 1986). Knowing the threshold energy needed to shatter a carbon atom and the distance each alpha particle of the triple track has traversed in the CR-39, the energy of the neutron that created that triple track can be estimated. The threshold energy of the neutron required to shatter a carbon atom to form a three-prong star is 9.6 MeV (Al-Najjar et al., 1986). Linear energy transfer (LET) curves are used to determine the stopping distance of alphas in CR-39 as a function of alpha particle energy. The photomicrograph shown in Figure 2b indicates that two alphas are carrying off the excess energy after the carbon has shattered. The distance between the center point and the prongs of the triple track is 7.81 μm. The LET curves for CR-39 indicate that the energy of the alphas is 1.83 MeV. The energy of the neutron that generated this triple track is estimated to be 13.25 MeV. This falls in the energy range expected for neutrons generated as the result of DT fusion. The double track indicated in

Figure 2a is comprised of a small track and a large track. Such tracks had been reported by Lipson et al. and are attributed to a 1 MeV triton and 3 MeV proton that have been emitted from the same space point and are the products of the D(D,P)T reaction (Lipson et al., 2000).

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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 $\times$ 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 per 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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Observation of Neutrons and Tritium in a Wide Variety of lenr Configurations: BARC Results Revisited

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1. Introduction: A four line news item on the historic Fleischmann-Pons (F&P) announcement carried by the 24 March 1989 issue of the *Times of India* newspaper triggered a flurry of activity at the Bhabha Atomic Research Centre (BARC) at Mumbai. Within days groups having expertise in diverse disciplines such as hydriding of metals, electrochemistry, isotope exchange processes in upgrading heavy water, fusion plasma experiments and neutron and tritium measurements, set up a variety of electrolytic cells having widely different geometrical configurations with a view to verify the extraordinary claim of F&P. The objective of the onslaught was to establish whether the F&P effect had indeed any nuclear dimension to it; at that point in time BARC was more interested in confirming the possible occurrence of nuclear fusion reactions at room temperature than in the "excess heat" aspect. Since neutrons and tritium were the commonly expected products of fusion reactions, these were the signatures that our experiments sought to detect.

BARC, being the foremost nuclear R&D centre in India with over 50 divisions and 3500 scientists and engineers, had the expertise and equipment readily available for study of almost every aspect of nuclear technology. Details of the various cells set up and the results of the neutron and tritium measurements carried out in the early years are documented (Iyengar, 1989; Iyengar & Srinivasan, 1989, 1990; Iyengar et al., 1990). The first reports on the confirmation of observation of neutron and tritium generation in the BARC lenr experiments were presented at the Fifth Int. Conf. on Emerging Nuclear Energy Systems held in Karlsruhe during July 1989 (Iyengar, 1989). A comprehensive Technical Note with 50 authors published in the August 1990 issue of *Fusion Technology* (Iyengar et al., 1990) describes in great detail the lenr experiments conducted at BARC during the first 8 months following the F&P announcement, inclusive of the gas/plasma loaded Ti samples studies (Srinivasan et al., 1990).

An interim progress report on "BARC Studies in Cold Fusion" covering the period April to September 1989 (Iyengar & Srinivasan, 1989), unambiguously confirming the occurrence of nuclear reactions at room temperature in deuterided Pd and Ti samples, was published at around the same time as the highly negative findings of the report of the "ERAB" Cold Fusion Panel (1989) set up by the US Department of Energy and played a historically key role in helping keep interest in the subject alive. During 1992–1995 some experiments were carried out with Ni-H systems which also indicated the production of tritium (Sankaranarayanan et al., 1995, 1996; Srinivasan et al., 1992).

Unfortunately, following global trends, lenr work at BARC too fell a victim to the highly skeptical view of the subject that gained credence at that time and studies in this controversial area of research were terminated by the mid 90s. But interestingly, following a 1 day brain storming workshop held in January 2008 at the National Institute of Advanced Studies in Bangalore (Srinivasan, 2008) which took stock of the new developments in the field, there has been a revival of interest in lenr studies once again in India.

In the present paper we revisit the "forgotten" BARC results of the early years and examine what lessons can be drawn from them two decades on, in the light of the new developments in the field.

2. Brief Description of the Electrolytic Cells and Experiments (Iyengar, 1989; Iyengar & Srinivasan, 1989, 1990; Iyengar et al., 1990): The Neutron Physics Division had a head start in the BARC lenr campaign because coincidentally a large cathode surface area (300 cm^2) Pd-D_2O electrolytic cell with 5 M NaOD electrolyte was already set up and ready for operation on 24 March 1989! This off the shelf ultra pure hydrogen generator with 16 Pd-Ag alloy tubular cathodes arranged along a circle (inner and outer nickel cylinders constituted the anode) had been procured from the Milton Roy company of Ireland for generating oxygen free deuterium for plasma focus type "hot fusion" experiments. On receipt of the F&P announcement two separate neutron monitors were quickly organized on either side of the cell and electrolysis commenced. A NE 102A plastic scintillator type fast neutron detector and a bank of three BF_3 counters embedded in a paraffin assembly constituted two independent foreground neutron monitors while a similar He^3 counter bank in paraffin served as background monitor. The first evidence of neutron production by this cell was obtained on 21 April 1989. As may be seen in Figure 2 of Iyengar and Srinivasan (1990), both the neutron monitors detected about a dozen peaks of varying magnitude in the neutron counts data.

Engineers of the desalination division set up a large cathode area (780 cm^2) five module bipolar electrolyzer with Pd-Ag alloy cathode plates and alternating porous nickel plate anodes (parallel plate geometry). The total volume of the NaOD electrolyte in the cell was 1 litre and max current capacity was 78 amps. The neutron physics division assisted with the neutron measurements using He^3 detectors and an NE102 plastic fast neutron detector. Within a few hours of commencement of cell operation a large burst of neutrons lasting about 2 minutes was recorded by both the foreground neutron channels; the background monitor did not show any change in count rate.

Most groups used cathode samples with minimal pretreatment using only normal cleaning agents readily available in laboratories. Only the chemists said they vacuum annealed the cathode material prior to deployment in the cells. The Analytical Chemistry division set up several cells using a variety of cathode samples: hollow Pd cylinder, a Pd ring, nickel-titanium alloy etc. Neutrons produced by two of their cells were detected by using the 1186 Kev neutron capture

gamma ray emitted by a sheet of gadolinium placed in front of a large Na(I) gamma detector from one of their cells. Figures 7 and 9 of Iyengar and Srinivasan (1990) show three large neutron spikes each emitted by the two cells.

3. Remarks on the Neutron Measurements and Results: Table I of Iyengar and Srinivasan (1990) summarizes details of the 11 electrolysis experiments in which both neutron and tritium production was observed. (The last cell was from the Indira Gandhi Centre for Atomic Research at Kalpakkam, which is a sister institution of BARC.)

Many cells (8 of 11) observed the first neutron emission on the first day itself! Neutron emission reported by most of the BARC groups in the 1989 experiments was generally in the form of spikes superimposed on a steady background. (Of all the neutron results reported in Iyengar & Srinivasan, 1989, 1990, and Iyengar et al., 1990, one result, namely that from Pd ring and Pd coil cathode cells reported by the Applied Chemistry Division, has since been withdrawn by the original authors. They had used a bank of 24 He^3 detectors embedded in a paraffin block and have since concluded that there may have been sparking in the counters resulting in erroneous data.) The exception to the general observation of neutron counts variation being in the form of spikes was the neutron results of a Ti cathode cell set up by the Desalination Division who reported continuous neutron production. A second exception was the neutron measurements carried out in 1994 on a newly procured Milton Roy cell (Pd-Ag alloy cathodes). As reported in the companion abstract in the present issue of *JSE* (Srinivasan, 2009), this cell yielded a low rate of neutron production throughout a 1 month period. Neutron production by this cell was confirmed by the neutron multiplicity measurements also.

Interestingly on several occasions neutron emission was observed from electrolytic cells hours or days after the cell current had been switched off; it is presumed that the cathodes remained partly charged with deuterium during this time in spite of cell current being off. This phenomenon is analogous to the "heat after death" phenomenon since noted during calorimetric measurements by other workers in the lenr field.

Neutron emission in the form of a distinct spike above background level was also observed from an unperturbed titanium deuteride disc just sitting on the table! Neutron multiplicity distribution analysis of this spike indicated that sharp bursts of 10s to 100s of neutrons each were produced by this target several times both within as well as outside the spike region (see Srinivasan, 2009, the companion abstract); such neutron bursts could be detected in spite of the fact that these counts were buried within the background counts because of their very low rate of occurrence.

4.1. Measurement of Tritium Levels in Electrolyte Samples: The tritium levels in the electrolyte samples collected after operating the cells for some days or weeks were measured by specialist groups either at the Isotope or the Health Physics division using well known liquid scintillation counting techniques applicable for low energy beta emitters taking the following precautions: (a) K^{40} free counting vials were employed to minimize background counts. (b) For higher

count rate cases, 0.1 to 2 ml of sample was added to the scintillator while for low count rate samples ≈10 ml was used. In the higher concentration samples pH was reduced by diluting them with double distilled water, in order to minimize chemiluminescence as well as quenching effects. Independently, whenever possible, these values were cross-checked with results obtained after "chemiluminescence cooling". (c) Commercially available Instagel scintillation cocktail was preferred over Dioxane as a solvent to minimize chemiluminescence interference effects. Prior to the commencement of electrolysis, a sample of the initial electrolyte was saved and counted along with each sample drawn during the course of the experiment. Micro distillation of the test samples was carried out whenever called for prior to addition of the scintillation cocktail.

To compute the excess tritium produced in each run, the following points were taken into account: (a) Initial tritium concentration in the stock D_2O which was measured in every case (it was typically a few Bq/ml); (b) to be on the conservative side the tritium carried away by the D_2 gas stream during electrolysis was neglected even though it is known that above 20°C the (T/D) ratio in the gas stream is comparable to that in the liquid phase; and (c) dilution effects due to periodic make-up of D_2O. Sec. 9 of Sankaranarayanan et al. (1995) gives a detailed summary of the procedures and precautions adopted for tritium assay.

4.2. Tritium Results: Tritium was observed in the electrolytes of 22 different electrolytic cells (see Tables I and II of Iyengar & Srinivasan, 1990). The maximum amount of tritium produced (55.6 KBq/ml corresponding to a total tritium yield of 13.9 MBq) was by the large Milton Roy cell. In general the total quantum of tritium generated by the various cells was in the range of KBq to MBq.

Although neutrons are measured online as and when they are emitted while tritium is measured subsequently as a cumulative quantity at the end of the electrolytic runs, there seems to be strong indication that both neutrons and tritium are generated "simultaneously" (Figures 3 and 7 of Iyengar & Srinivasan, 1990). Most groups collected electrolyte samples every few days and these showed the presence of tritium invariably only in samples collected after neutrons were recorded. In those cells where both neutrons and tritium were observed, the neutron to tritium yield ratio was in the region of $\{(10^{-7})\}$ (except for the Applied Chemistry division result of Table I, Iyengar & Srinivasan, 1990, whose neutron measurements have since been withdrawn as mentioned earlier). Most of the cells included in Table I of Iyengar and Srinivasan (1990) have yielded this unique characteristic signature of lenr devices which has since also been reported by many other laboratories.

5. Studies on Deuterium Gas/Plasma Loaded Ti Samples (Srinivasan et al., 1990): Five different types of gas/plasma loading approaches were employed at BARC for loading deuterium into titanium samples. Presence of tritium if any on the surface of the samples was established subsequently both through autoradiography as well as direct counting of the beta particles emitted by the tritium as well as through the Ti K-alpha X-rays. A very fortuitous characteristic

of titanium is that the betas emitted by tritium have energy up to 18 Kev and so are able to excite the 4.3 Kev K-alpha line of Ti which can be easily identified by standard X-ray detectors.

(a) In the first approach which used standard procedures for gas loading, titanium samples were first thoroughly cleaned using acids, then vacuum annealed, degassed and then heated to 800°C using a resistance furnace and then allowed to cool in D_2 gas atmosphere. In the lathe shavings (or chips) experiment described in Kaushik et al. (1990) and Srinivasan et al. (1990) deuterium loading was carried out by this procedure. In this experiment after loading, the deuterated chips were dropped directly into liquid nitrogen; subsequent measurements indicated presence of large amounts of tritium (10s of MBq) in four out of about 1000 chips! The autoradiograph of these four chips showed several remarkable hot spots which could be repeatedly radiographed over several months (Kaushik et al., 1990). The chips belonging to the control lot which were not loaded with deuterium nor treated in liquid nitrogen did not show presence of any tritium.

(b) In the second approach machined Ti electrode samples (discs and cones) were heated in deuterium gas using an induction heater. Some of these gave characteristic spotty autoradiographs. Measurements using X-ray detectors confirmed the presence of tritium in the spotty regions especially along the edges which displayed a nice ring of dots along the periphery in case of disc and in case of a cone an intense spot corresponding to the tip of the cone. Iyengar (1989), Iyengar and Srinivasan (1989, 1990), Iyengar et al. (1990), and Srinivasan et al. (1990) carry these images.

(c) The third method of deuterium loading was through a DC glow (plasma) discharge between a pair of titanium electrodes which leads to absorption of deuterium by the cathode.

(d) The fourth method employed high voltage discharge shots in a plasma focus device wherein a large Ti rod served as the central anode. In this method a very hot and high density deuterium "plasma focus" is formed just above the tip of the rod, following a Z-pinch initiated magnetic compression phenomenon. During this process the top surface of the anode is subject to transient but intense magnetic and electric fields and gets very effectively cleaned resulting in efficient absorption of deuterium on the surface region, in spite of the fact that the rod is positively biased. Since the electromagnetic fields last hardly for a microsecond the anode rod which remains exposed to the gas in the chamber after the discharge shot gets deuterated on the surface. One Ti rod which was subjected to 50 such plasma focus shots was found to contain massive amounts of tritium (14.5 MBq) which remained entrenched on the surface for more than a year subsequently (Rout et al., 1991)! The very impressive autoradiographic image given by this rod can be seen in Iyengar (1989), Iyengar and Srinivasan (1989, 1990), Iyengar et al. (1990), and Rout et al. (1991).

(e) In the so-called "aged TiD targets" study, anomalously large amounts of tritium (varying from a fraction of a MBq to a couple of hundred MBq) were detected on the surface of all 12 of 12 TiD targets which had been manufactured several (9 to 19) years earlier by loading deuterium onto thin Ti films coated on copper backings, for use as targets in accelerator experiments. The presence of tritium was confirmed through five different measurement techniques inclusive of autoradiography. Every one of the 12 "aged" targets gave a very impressive coin like round image. But interestingly the images were quite uniform, not spotty as in other Ti samples. This is commented upon later. We postulate that the tritium could have been produced by lenr processes in the TiD thin films even while merely sitting in the drawer over the years! The possibility that tritium could have entered as contamination during the manufacturing stage of the TiD targets at the suppliers' end (nine were from M/s Amersham company of UK and three had been fabricated at BARC by the isotope division) has been ruled out after discussions with the manufacturers. Details of this study are available in Sec. 5 of Iyengar and Srinivasan (1990).

6. Ni Hydrogen Experiments (Sankaranarayanan et al., 1995, 1996; Srinivasan et al., 1992): Experiments were initiated with light water electrolytic cells using Ni cathodes and K_2CO_3 solutions as electrolyte following reports of observation of excess heat in such systems by Mills and Kneizys (1991) and other groups in the early 90s. Although observation of excess heat in open electrolysis cells with Ni cathodes and K_2CO_3 electrolyte was reported at the ICCF-3 in Nagoya in 1992 (Srinivasan et al., 1992) we have since come to the conclusion that the apparent excess heat reported at that time can be attributed to hydrogen-oxygen recombination effects within the open cell.

BARC groups were however probably the first to report observation of tritium in light water cells. At Nagoya we reported that 18 of 29 cells indicated tritium levels in the range of 46 Bq/ml to 3390 Bq/ml after a few weeks of operation. The high value of 3390 Bq/ml was produced in a cell in which D_2O to the extent of 25% was added but three other identical cells with 25% D_2O did not give any tritium. One cell with enriched (54% enriched in Li6) Li_2CO_3 in H_2O gave 1454 Bq/ml whereas two others with the same type of cathode and electrolyte gave no tritium whatsoever. Cell no. OM-3 even showed a steady increase of tritium level reaching a comfortable value of 224 Bq/ml over a period of 4 weeks (see Figure 8 of Sankaranarayanan et al., 1996).

Some skepticism was expressed even within BARC circles regarding the reliability of low level tritium measurements in light water cells, suspecting that the result could have been either due to cross contamination at the tritium measurements lab where samples from different research groups were handled or it could possibly have been from "tritium in the BARC atmospheric air". Hence starting in June 1993 a completely new set of Ni light water cells were set up and studied at two different sites over a period of 3 months; six cells were set up at the Chemical Engineering Division and 17 cells (5 at a given time) at the Process

Instrumentation Division, specifically for the purpose of verifying tritium production. This time a new captive liquid scintillation counting facility was installed in the Chemical Engineering Division and extra caution observed to avoid any possible external contamination. All electrolyte samples were micro distilled taking care to avoid alkali carry over before mixing with scintillation cocktail for counting. With this equipment tritium levels down to 0.5 Bq/ml could be measured. Details regarding these repeat measurements are presented in Sankaranarayanan et al. (1995). In all, 10 of 23 of the new cells showed low levels of tritium in the 0.5 to 4.8 Bq/ml range. In three of the Chemical Engineering Division cells from which samples could be drawn online without disturbing cell operation, an intriguing saw tooth type oscillatory variation of tritium levels of the electrolyte was observed. Sankaranarayanan et al. (1996) discuss more about this observation, pointing out that such oscillatory variation of tritium levels in electrolyte has been observed by others in Pd-D_2O cells also.

During 1994–1995 some experiments were also conducted with self heated thin Ni wires in a hydrogen gas atmosphere by subjecting the wires to several cycles of hydrogen absorption–desorption. The wires were then cut into 1 cm bits and analyzed for tritium content after dissolution. The results showed again a non-uniform production of tritium along the length of the wire with some sections showing no tritium at all while others contained significant amounts; one bit had as much as 2333 Bq. Details are presented in Sankaranarayanan et al. (1995).

7. Comments, Implications, Speculations and Suggestions for Future Studies: It is prudent to re-examine the BARC results in the light of the new information that has since become available.

Our results clearly demonstrate that for neutron emission to take place in lenr configurations one does not need the "high degree" of deuterium loading that seems to be a prerequisite for excess heat production. Other workers in the lenr field have since also come to a similar conclusion.

The fact that a dozen groups of novices set up cells using Pd samples lying about in the laboratory and yet detected neutrons and tritium within the first day is interesting. Table I of Iyengar and Srinivasan (1990) which tabulates the "switch on time" for each electrolysis experiment shows that 7 of the 11 cells listed detected the first neutron signal within 9 hours, one gave within 24 hours and the balance three cells within a few weeks. Of course there were several other cells which did not emit any neutrons at all. Like most other workers in the field, the BARC groups also could not replicate the results. Cells which gave neutrons initially stopped yielding any more neutron signals; this tells us something about the crucial role of "poisoning" effects during electrolysis which has been noted by others too.

At least in the case of titanium, tritium was observed in localized hot spots in three different types of gas/plasma loading experiments as described earlier. All these used machined cold worked targets and careful scrutiny of the autoradiographic images indicates that tritium is found to a maximum extent where there has been severe cold work caused lattice defects. It does appear that somehow

cold working has been responsible for creating "Nuclear Active Environment" (NAE) sites that Storms (2007) has postulated. In contrast the tritium in the thin film Ti targets of the aged targets study is uniformly distributed. One can draw one's conclusions regarding the significance of these observations.

Why is it that we see spots in which tritium is concentrated only in titanium but not in Pd? The answer to this is possibly given by the very long life time of the autoradiographs we have observed in the case of titanium samples but never in Pd. This means tritium is very immobile in Ti but not so in Pd. We therefore speculate that at the time of formation tritium is possibly being generated in local hot spots (the NAEs) in Pd also but in course of time the tritium diffuses in the Pd lattice and gets distributed. The reported observation of live thermal hot spots on the Pd cathode during electrolysis reported by some groups such as Swartz and the SPAWAR group reinforces our contention.

It is instructive to examine in an integrated fashion the following four separate findings that have emerged from the BARC studies: (a) Simultaneous production of neutrons and tritium (mainly in Pd electrolysis experiments). (b) Branching ratio anomaly, namely (n/T) ~ $(10)^{-7}$; at least one Ti cathode cell has also given rise to the anomalous branching ratio. (A number of other groups in the world have also independently confirmed the branching ratio anomaly.) (c) The spotty nature of tritium containing sites in titanium targets as already discussed above. (d) Production of neutrons sometimes in bursts of 10s to 100s of neutrons. This is elaborated on in great detail in the companion abstract (Srinivasan, 2009).

If the "indication" of simultaneous production of n and T, is viewed in the light of burst neutron emission, it could be speculated that tens of millions of tritium nuclei are produced along with a few 10s to 100s of neutrons in a local hot spot or NAE (possibly in a time span of less than a nano second). We thus speculate that once an NAE is formed a rapid cascade of several million tritium producing nuclear reactions takes place in rapid succession in a local region—a sort of chain or cascade event—during which process for every ten million tritium nuclei generated one neutron is also emitted as a very low probability offshoot side reaction event!

One criticism of this line of argument could be that one component of the "evidence" (simultaneous emission of n and T) is from electrolysis experiments with Pd cathodes while the other component (namely spotty nature of tritium bearing sites) is with gas loaded Ti targets. There are however a limited number of results which do overlap the two broad classes of experiments.

It is conceded that the evidence for the chain reaction scenario is not "water tight" but it may be worth pursuing such a speculative line of thought if only to see where it leads! Perhaps one could design and carry out specific experiments to eliminate or confirm individual components of this highly speculative scenario.

Lastly production of tritium in nickel light water cells is very intriguing and deserves attempts at replication especially since the design and operation of such light water electrolysis cells is very simple and inexpensive; students at universities can easily do it, but one does need access to a qualified lab where samples can be sent for carrying out the tritium measurements.

Interestingly nickel too has given evidence of non-uniform behavior. Here again the tritium bearing localized regions are possibly because hydrogen (and tritium) are less mobile in Ni than in Pd.

Acknowledgment: The author wishes to place on record the significant contributions of a large number of his former BARC colleagues who are co-authors of many of the papers from which the work reviewed here has been drawn.

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Excess Heat and Electrical Characteristics of Type "B" Anode-Plate High-Impedance Phusor LANR Devices

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Introduction: The binary alloy, PdD_x, has an electrical resistance which is well studied (Bambakidis, 1968, 1969; Baranowski, 1969; McKubre & Tanzella,

2005; McKubre et al., 1990; Otterson, 1969; Schreiber, 1990) and is a biphasic function of loading ratio, x. Therefore, the ratio of metallic electrical resistance of the Pd to its "initial unloaded" value at the same temperature, R/R_0, is used to estimate loading (McKubre & Tanzella, 2005; McKubre et al., 1990). Loading is important to lattice assisted nuclear reactions (LANR) because a loading ratio of ~0.85 D/Pd, is required to generate excess heat from an active LANR material, although issues of confinement time (weeks), adequate deuteron flux, requisite activation energy, maintaining structural lattice integrity, phonon support, and maintaining optimal operating point operation are also critical, but are ignored for the moment (Swartz, 1992, 1994, 1997, 2006). H- and D-drift experiments indicate a fractional electronic charge dressing of the protons so that there is a fractional charge in the range of +0.42 to +0.7. Luo and Miley (2003) have considered that the fractional positive charge is a dynamic property, associated with the hopping process within the lattice. The implication is that deuterium ions are at least partially screened by the conduction electrons from the palladium, even for loading ratios less than $x = \sim 0.55$. For pure palladium, reciprocal space analysis shows six bands near the Fermi surface. Three bands cross through it, and another three are nearby, one of which becomes decisive at higher loading. Electron-phonon scattering is usually considered, while electron-electron scattering is not. Also, usually ignored is the role of Pd vacancies, which have similar incremental resistivity effects (Xu et al., 1998). The electrical resistivity of palladium is described by the Bloch-Gruneisen formula, except for electron-electron scattering.

As hydrogen is added to palladium, while loading continues up to $x = \sim 0.5$, the hydrogen donates its electron to fill up the unfilled palladium d-shell (0.36 holes in its d-band revealed by deHaas-vanAlphen experiments), its electron enters a hole thereby increasing resistance. This is heralded by the decreasing Debye temperature indicating a reduction in the total number of available electronic carriers. There is an initial linear rise in the resistivity ratio. Loading above $x = 0.5$ takes energy. By $x = 0.6$, the electron donation from deuterium to the lower lying bands end, as the bands become full. Gap energy is now required, as the filling shifts to the "sixth band" (Luo & Miley, 2003). With that, there is an increase in charge carriers, and the observable decrease in the electrical resistivity ratio making the resistivity ratio-loading curve biphasic. Loading has been examined several ways. For example, Otterson and Smith (1969) have done meticulous work using a graphite anode using retention studies and resistivity ratio measurements carefully done at high loading, and have noted that the palladium is two inter-penetrating face-centered cubic lattices. They have proposed H/D movement from the interstitial octahedral sites of the palladium lattice to the tetrahedral sites. Other possibilities include double octahedral site occupancy and new phases. Asami et al. (1997, 1998) have examined the lattice constants during the phase change from alpha to beta phase (and did not find any other higher-loading putative phase up to loading ratios of $x = 0.9$). Important, but less often considered, are the inhomogeneities in the D distribution, polycrystalline Pd (loads poorly),

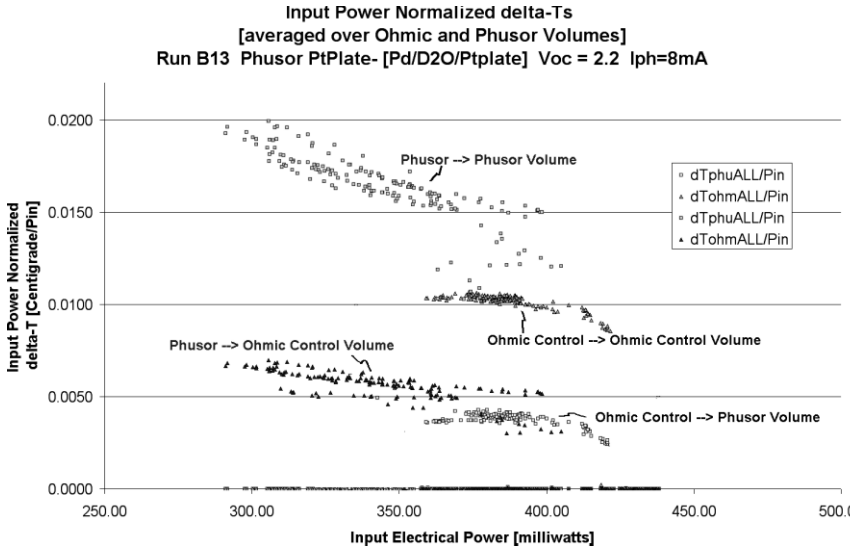

Fig. 1. Input power normalized delta-T of a Type "B" LANR device and control.

and roles of dislocations, fractions, grain boundaries, and competing hydrogen (H vs. D) which impact D loading- and loss-rates, flow, and distributions (Swartz, 1994, 2006, 1992).

Results and Discussion: This paper reports on the LANR behavior and metallurgical electrical behavior of Type "B" (anode plate) Pd/D_2O/Pt Phusor® type LANR devices driven at their optimal operating point, using 4-terminal Pd conductivity, near-IR, calorimetric and heat flow measurements. Two current sources are used to drive and interrogate the device. Figure 1 shows the excess heat generated by the Type "B" Pd/D_2O/Pt Phusor® LANR device, based on the input power normalized delta-T data of ~175%, compared to the output heat created by dissipation from an ohmic control in the same electrical circuit. At initiation, the wet electrical resistance of the heavy water electrolytic cell was 253.6 kilohms. This experiment consisted of increasing input electrical currents, in pulses, such as seven pulses to the ohmic control of differing input electrical power, and then 14 different power levels applied to the cathode. The latter received from 1 microampere up to 20 milliamperes, which produced a peak potential of 99.7 volts between the cathode and anode. The peak power dissipated was 1.99 watts.

The excess energy is greater than that available by energy storage, and it is not energy storage based on time integration. The excess energy can only have a nuclear origin because its magnitude is beyond the chemical energies available even including all reactants and their containers. There are negligible changes in electrodes, no substantive change in reactants (except loss of water), and no significant products (corrosion products, flocculation, chemical deposition).

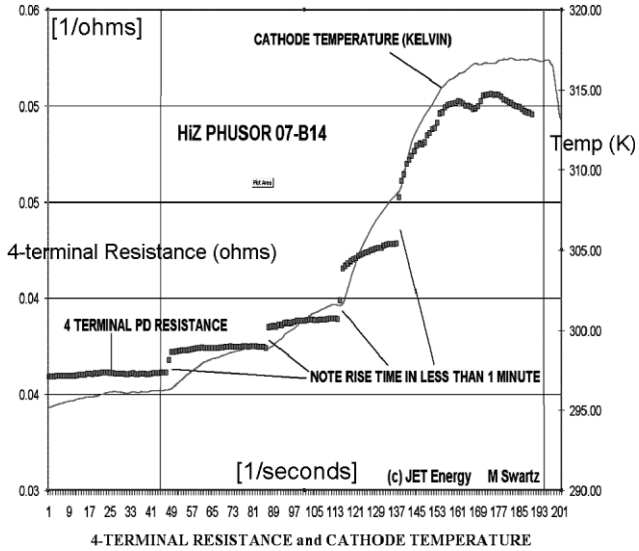

Fig. 2. Pd resistance and temperature of a Type "B" Phusor LANR device.

Applying an electric field intensity to the solution and cathode resulted in a near-linear rise in 4-terminal electrode resistance. This was not seen when the ohmic control was driven. At the higher levels of loading, excess heat was observed. Importantly, as Figure 2 shows, during synchronous 4-terminal measurements of palladium transconduction, while driving the 6-terminal Type "B" LANR devices, there are two temporal components to intrapalladial conductance decreases to loading for these 6-terminal Type "B" Phusor®-type LANR devices. The shorter time constant (<5 seconds) cannot be due to deuteron loading.

There are several possibilities, including possible electrodynamic ordering of the intrapalladial deuteron lattice, or another electrodynamic effect which controls palladium electric conductivity. It might have a possible component of cross talk through the palladium, and efforts are underway to semiquantitatively address and remove this as an issue. It may also result from a momentum change from the applied electric field intensity upon one, or both, of the charge carriers, or their scattering. If, when improved geometry is available, with both metachronous and synchronous extensive testing, this persists, then there are two possibilities. To the degree that axial electronic or deuteron electrical conduction in the cathode goes through the surface of the electrode, the application of the power source driving the LANR may cause incremental loading, polarization, and structural (including through plasmons, polarons) changes that interfere with the surface conduction. On the other hand, to the degree that axial electrical or deuteron conduction in the Pd LANR cathode goes through the bulk of the 1 mm diameter wire (more likely based upon the actual magnitude observed of the

devices which is in the range of ~50 milliohms), the application of the power source driving the LANR may cause a field- or polarization-induced coherence change in the organization of the deuteron lattice, thereby interfering with the volume conduction. Our initial calculation based on the values of the resistivity support the latter.

Using synchronous 4-terminal measurements, prior to this excess heat, there is a supralinear rise of intrapalladial electrical resistance for applied voltages (to the solution) >78 volts. This, and the electrodynamic initial changes, may have a triggering role in LANR. Finally, at high loading, previously an instability oscillation has been noted in the resistivity ratio (Luo & Miley, 2003), which we have confirmed. We propose that this oscillation may be an observed electrodynamic component.

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Nuclear Transmutation of Isotopes in Biological Systems (History, Models, Experiments, Perspectives)

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1. Introduction and Prehistory: The hypothesis about the possibility of nuclear transmutation of chemical elements and their isotopes in biological systems has been frequently discussed during the last decades. This problem is one of the most mysterious in modern nuclear physics.

The issue of transmutation and synthesis of chemical elements during the "pre-nuclear period" has its own history and mythology, its own proponents and critics. With the discovery of the atomic structure and the nature of subatomic interaction, it became more obvious that, although all chemical features of the elements are caused almost exclusively by the behavior of valence electrons, still, the very nature of these elements (and, ultimately, the characteristics of valence and other electrons of the outer shell) is tied to the nuclear characteristics of the isotopes.

The series of works by Louis C. Kervran holds a special place in the chronology of transmutation of chemical elements in biological objects. Effectively, he was the first scientist of the post-nuclear era, who conducted systematized research of possible transmutational processes of chemical elements in biological objects. In his works Kervran gave numerous examples of unusual changes in the chemical composition of various biological objects, which occurs during their growth. He explained these changes on the basis of existing concepts of transmutation of chemical elements and different isotopes. Kervran analyzed possible ways of transforming elements and isotopes using common sense algebra rules for nucleons—the unchanged number of protons and neutrons in these transformations. This approach does not raise major objectives.

From the other hand, Kervran's perception of the nuclei structure and possible ways of their transformation was very different from customary and contemporary views in nuclear physics. He postulated the possibility of reversing the nuclear reactions in changing external conditions (i.e. inversion of potassium and calcium concentration in the environment). However, the reversibility of these processes is incompatible with the law of preservation of energy. He considered the process of the nuclear transformation as taking place on the cell's surface or in the volume of the membrane given the catalyzing power effect of an unknown enzyme.

In our opinion there are no reasons to separate the process of transformation of isotopes and elements during biological transmutation from the general physical concept as a process of transformation of isotopes, governed by the laws of physics. We believe that all the observed isotopic effects (in case they are real and supported by adequate and reliable measurements) can be characterized as

the "regular" process of transmutation of isotopes and elements, which occurs in biological systems, and the efficacy of which is determined precisely by the specifics of such systems.

2. Experimental Investigation of Fusion of Stable Isotopes in "One-Line" Growing Microbiological Cultures and in Optimal Growing Microbiological Associations: In this work, the processes of transmutation of isotopes in growing biological systems are examined from three different aspects—as totality of experimental facts of low energy isotopes transmutation, as a process based and analyzed from the perspective of nuclear science, and as a process studied from the point of view of biochemistry of live systems.

The results of successful experiments on transmutation of stable isotopes (e.g., $Mn^{55} + d^2 = Fe^{57}$, $Na^{23} + P^{31} = Fe^{54}$) in both "on-line" microbiological clean cultures (like *Escherichia coli* and *Saccharomyces cerevisiae*) and microbe syntrophin associations are presented. The objective of conducted experiments was detection and study of the possibility of running a low-energy transmutation of isotopes in growing microbiological cultures. Experiments were conducted using several bacterial cultures (*Bacillus subtilis, E. coli, Deinococcus radiodurans*) as well as the yeast culture *S. cerevisiae*. A typical series of experiments on nuclear transmutation of isotopes in growing microbiological cultures involved simultaneous growing of separated parts of the same culture in several (e.g., four) flasks (Figure 1).

It was shown that the transmutation process during the growth of such microbiological cultures had taken place, but its effectiveness had been low (see Figure 2, left panel):

$$\lambda = N(Fe^{57})/N(Mn^{55})\Delta t \approx 10^{-8}$$

(synthesized Fe^{57} nuclei per s and per single Mn^{55} nucleus) in the case of the reaction with light isotope $Mn^{55} + d^2 = Fe^{57}$.

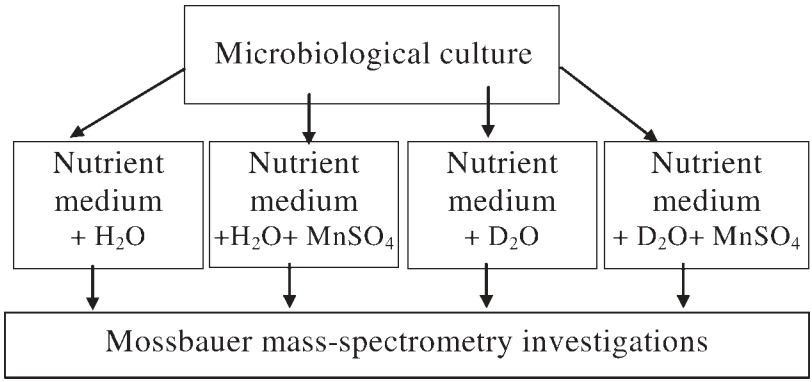

Fig. 1. A typical scheme of "cross-experiments" for studying the effect of nuclear transmutation $Mn^{55} + d^2 = Fe^{57}$of isotopes in growing microbiological cultures.

The same low effectiveness was observed for reactions with more heavy isotopes (e.g., $Na^{23} + P^{31} = Fe^{54}$ and $Cs^{134} + p = Ba^{134}$). There are two main reasons of low effectiveness of nuclear transmutation in "one-line" microbiological cultures:

- The relatively low efficiency for creating these reactions is the result of the narrow interval of optimal functional individual characteristics for initiating nuclear activity in any "one-line" type of culture. Each of the "one-line" cultures individually requires a set of specific conditions (temperature, hydrogen ion exponent pH, balanced contents of nutrient medium, etc.) for achieving optimal metabolic conditions during the complete period of growth. Such conditions are often absent in real experiments.
- During the growth of a "one-line" culture, we hypothesize that processes involving forms of auto-intoxication of nutrient media by metabolic products take place. This hypothesis is consistent with forms of growth impairment.

In a contrast to these "one-line" cultures, we have investigated microbiological associates (MCT compound) that include great numbers of types of different cultures. These cultures are in a state of natural complete symbiosis and grow as a total correlated multisystem. In this experiment the large amplitude of the Mossbauer resonance at the same mass of investigated dried biological substance was observed and measured (see Figure 2, right).

In this case the coefficient of transmutation is the following:

$$\lambda = N(Fe^{57})/N(Mn^{55})\Delta t \approx 10^{-8}$$

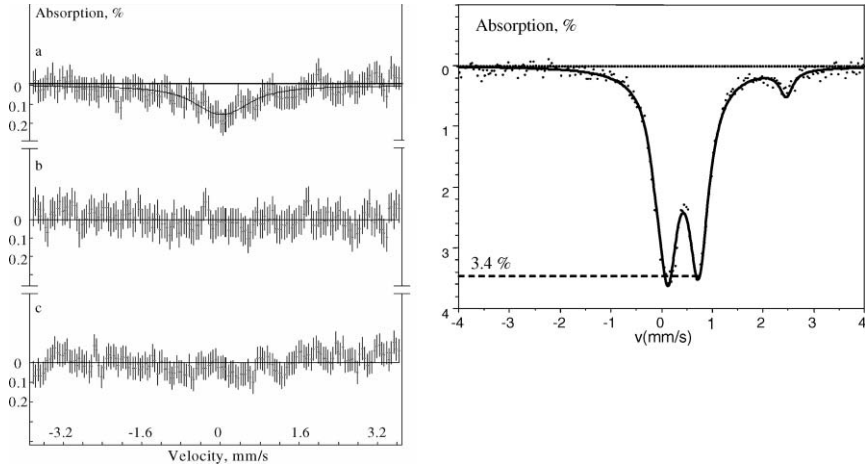

Fig. 2. The Mossbauer spectra for culture *Saccharomyces cerevisiae* grown: (a) in D_2O with Mn^{55}; (b) in H_2O with Mn^{55}; (c) in D_2O without Mn^{55} (left) and for MCT compound grown in D_2O with Mn^{55} (right).

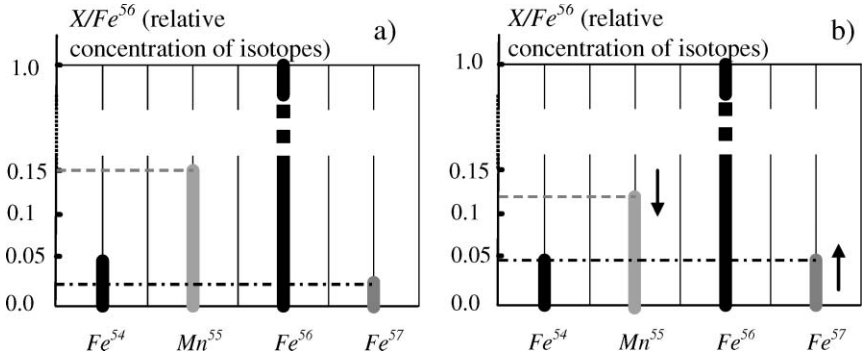

Fig. 3. Mass-spectra of iron-region of microbiological associations (dried biological substances) that were grown in control nutrient medium with H_2O and Mn^{55} (case a) and in experimental nutrient medium with D_2O and the same quantity of Mn^{55} isotope (case b). The process of increasing (↑) of concentration of Fe^{57} isotope is accompanied by decreasing (↓) of concentration of Mn^{55} isotope. Here X = Fe^{54}; Mn^{55}; Fe^{57}.

(synthesized Fe^{57} nuclei per s and per single Mn^{55} nucleus). For verification of these results, additional examinations of the isotopic ratio of the same dried biological substances (both control and transmutated) were conducted by TIMS. These results are presented in Figure 3.

3. Experiments on Controlled Decontamination of Active Isotopes in Biological Cells: The process of decontamination (deactivation) of radioactive waste through the action of growth in microbiological systems is connected with transmutation of long-lived active nuclei to different non-radioactive isotopes during growth and metabolic processes involving MCT granules.

The research has been carried out, based on using the identical distilled active water with Cs^{137} isotope. In the experiments the MCT compound was placed in seven glass flasks. In six different flasks, different pure K, Ca, Na, Fe, Mg and P salts as single admixture were added to the active water. These chemical elements are vitally necessary for any cultures. The cultures were grown at the temperature 20°C. Activity of all flasks has been measured every 7 days by precise, large amplitudes, using a Ge detector.

We have observed increased rates of decay of Cs^{137} isotope in all experiments with MCT and with the presence of different additional salts during more than 100 days. In the control experiment (flask with active water but without MCT), the "usual" law of nuclear decay applies, and the life-time was about 30 years.

The most rapidly increasing decay rate, which occurred with a lifetime $\tau^* \approx 310$ days was observed in the presence of Ca salt! The results of investigation of change of relative activity Q(t)/Q(0) of isotopes in this most optimal case are presented in Table 1.

The biological and physical aspects and mechanisms of nuclear transmutation of different stable and active isotopes in growing biological systems (Vysotskii & Kornilova, 2003, 2009) are also discussed in details.

TABLE 1
Deactivation of Cs^{137} Isotopes in Optimal Case (MCT + Active Water + $CaCO_3$ Salt)

	Start	Finish of experiments (in 100 days)			
Isotope, energy (keV)	N_1, registered events per 10^3 s	N_2, registered events per 10^3 s	Error, absolute (relative)	Natural decay per 100 d	Change $(N_2 - N_1)/N_2$
Cs^{137}, 661.7	266,900	216,800	±478 (±0.2%)	–0.6%	–24%

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Physical Model and Direct Experimental Observation of Water Memory and Biophysical Activity of Magnetic-Activated Water

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Introduction: Water is one of the most mysterious chemical compounds. Anomalous properties of water became long ago a classical example of the manifestations of characteristics of nontrivial systems.

Up to now, there are no adequate answers to the questions about:

- spatial structure of water on molecular and supermolecular levels;
- existence of numerous paradoxes of water memory and the nature of water memory;
- duration of water memory and possibility of its control.

We performed a cycle of complex studies of activated water and water memory (Vysotskii & Kornilova, 2004), by using the activator of water, which was earlier studied by us (Vysotskii et al., 2005) and allowed us to obtain a number of results in the whole spectrum of physical, biological and nuclear applications.

1. Physical-Molecular Properties of Activated Water: Water was activated by the action of nonionizing Molecular Resonance Effect Technology (e.g.,

Vysotskii et al., 2005). Investigated activator of water is the stationary source of low-frequency (about 7–8 Hz) resonant electromagnetic field with composite space structure and very weak amplitude (about 1 Oe). It was discovered in our detailed physical experiments that under the action of this irradiation there are very essential modifications of the basic physical-molecular and biophysical properties of distilled water.

2. Anomalous Electrodynamic Characteristics of Activated Water: In the process of studies, we determined the electrodynamic properties of activated water as functions of three basic parameters:

- the water activation duration,
- the water storage duration after the activation,
- the temperature of activated water storage.

The influence of some of these parameters was investigated comprehensively (e.g., the influence of the storage duration and the storage temperature after the activation).

In Figure 1a the results of the base studies of the electrodynamic characteristics of initial nonactivated distillated water completely analogous to water which was then subjected to the procedure of activation are presented. The studies were carried out at 20°C.

It follows from these results that the initial distillated water has a low value of conductivity, $\sigma \approx 3.10^{-5}$ S/cm^2, and the dielectric permittivity close to the "standard" one, $\varepsilon'(\omega) \approx 90$, at the frequency of alternating electric current in the range $\omega \geq 10^3 - 10^7$ Hz. This value of the dielectric permittivity well agrees with the Debye mechanism of orientational polarizability of independent molecules of water. The maximum value of the dielectric loss tangent $(\mathrm{tg}\delta)_{\max} \approx 120$ and corresponds to a frequency of 1522 Hz. With decrease in the frequency to $\omega < 10^2$ Hz, a sharp decrease of the conductivity and a very sharp monotonous increase of the dielectric permittivity were registered. In the studied region of superlow frequencies (at $\omega \leq 10^{-1}$ Hz), the effective dielectric permittivity reaches a very great value $\varepsilon'(\omega) \approx 10^8$.

In Figure 1b and c we present the specific features of the electrodynamic characteristics of water activated for 30 min and stored up to the time moment of the measurement at a temperature of 20°C and 40°C. It is seen that these samples of water preserve some general regularities (a sharp decrease of the dielectric permittivity and the conductivity on the activation of water and their gradual recovery in the process of storage) and, at the same time, reveal the significant differences such as a significantly faster relaxation of the parameters with increase of the storage duration. In particular, for 5 h of the storage, the maximum value of the dielectric permittivity and the conductivity grew by 200% (Figure 1b).

One of the most important problems is the determination of the duration of "the memory of water" on the basis of the performed experiments. It is seen from our experiments that the duration of relaxation T_W of the mentioned electrody-

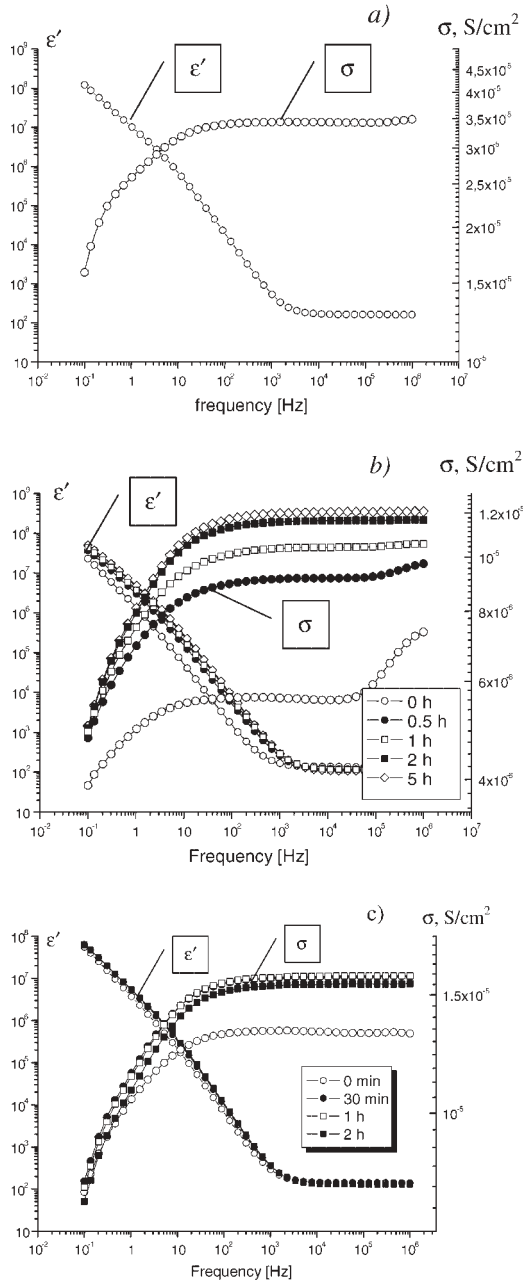

Fig. 1. Dielectric permittivity ε′ and conductivity σ of a water versus the frequency: (a) initial non-activated distilled water at 20°C; (b) the same distilled water activated for 30 min and stored at a temperature of 20°C; (c) the same water activated for 30 min and stored at a temperature of 40°C.

namic characteristics of activated water becomes very great (at least 5–7 days) at a comparatively low temperature (at 5°C). With increase of the temperature of the storage, this duration rapidly decreases. The duration of relaxation is 10–15 h at a temperature of 20°C and is equal to at most 4–6 h at a temperature of 40°C, close to the temperature of a human body. These results qualitatively agree with the calculations of water memory performed in our works (Vysotskii & Kornilova, 2004; Vysotskii et al., 2005, 2009).

3. Anomalous Viscosity and pH Characteristics of Activated Water: Viscosity is one of the most important characteristics of water. The particular meaning of the viscosity of water in any physical and biophysical systems is related to the transport functions of water and to the dependence of the motion and the evolution of macromolecules, ions, cells, viruses, and other microobjects on the properties of water, in which they are placed in alive organisms.

To study the influence of the activation of water on its viscosity, we executed several series of measurements of the dynamical viscosity η as a function of the applied stress τ with different fractions of water (the initial nonactivated distillated water and an analogous water activated for different time intervals) at two temperatures (20°C and 36.6°C).

In Figure 2 we present the results of studies of the viscosity coefficient for initial distillated nonactivated water and for the samples of water which were

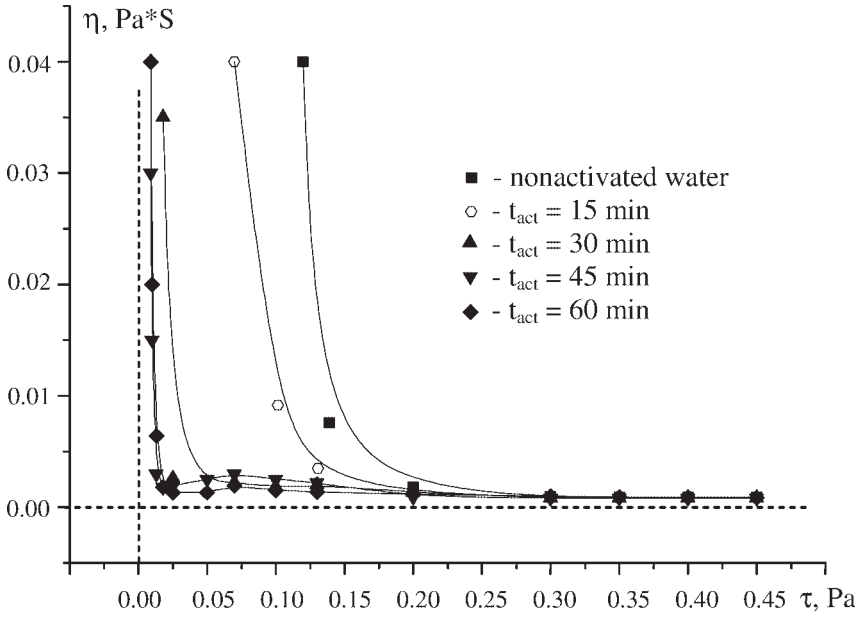

Fig. 2. Viscosity η of nonactivated water and four fractions of activated water in the region of small shear stresses τ at a temperature of 36.6°C.

obtained for the duration of activation of 15, 30, 45, and 60 min and were at a temperature of 36.6°C in the process of measurement. With regard for the fact that the anomalous properties of activated water relax rapidly with increase of the temperature, the measurements were carried out at once after the activation of water.

The change in the dispersive electrodynamic properties of water can render a very strong influence (by means of a modification of the electrostatic forces between separated charges and forces of the van der Waals type defining the interaction of the systems of neutral atoms and molecules) on the long-range interaction of such basis elements of alive systems as cells, viruses, biological macromolecules, enzymes, etc.

Viscosity, surface tension, and other mechanical properties of water which play a very important role in the processes of vital activity turn out to be directly related to the electrodynamic characteristics of water.

Very important is the circumstance that the viscosity of activated water in the region of very small shear stresses at the vitally important temperature 36.6°C, like the case of a lower temperature of 20°C, is by several orders less than that of ordinary (nonactivated) water.

During our investigations the sharp increasing and time-dependent oscillations of pH exponent during several weeks in activated water were observed (see Figure 3).

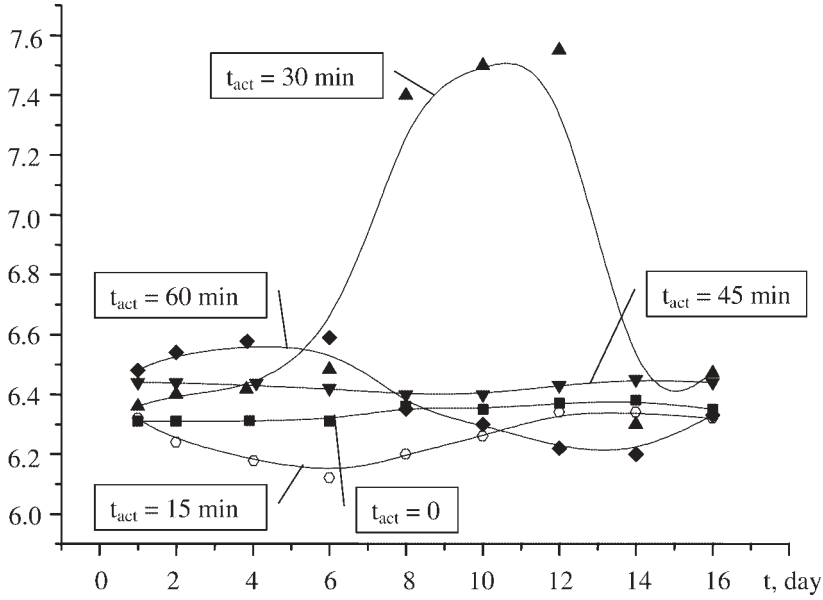

Fig. 3. Influence of the water activation duration on pH depending of the time of its storage at a temperature of 20°C.

It was discovered that duration of internal storage of all these abnormal characteristics of activated water equals several days or weeks at low temperature (close to 0°C). The problem and concrete quantum-mechanical and electrodynamical mechanisms of long time memory of activated water were studied earlier (Vysotskii & Kornilova, 2004; Vysotskii et al., 2005).

Potent effect of activated water on prophylaxis and treatment of two kinds of oncology diseases of mice are discussed. Effectiveness of action of such activated distilled water approximately equals action of chemotherapy! The theoretical biophysical model of strong action of magnetic-activated water on the process of cloning and growth of pathogenic microorganisms and the results of direct microscopy observation of such action are presented also. The problem of influence of activated water on the effectiveness of biotransmutation in growing microorganisms is also discussed.

Acknowledgment: We acknowledge and are grateful to New Energy Institute (San Rafael, California, USA) and personally to its executive director Steven B. Krivit for the travel grant for participation in 2009 ACS New Energy Technologies Symposium and presentation of this report.

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