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Experiments and Methods in Cold Fusion

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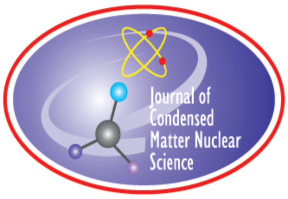

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Preface

It is again my pleasure to welcome this new volume of the journal. It includes only three papers, in order to speed up the publication of the papers. It is much better to publish papers as soon as they are ready than wait for a larger volume.

Volume 32 includes an experimental paper, one theoretical work and one on public policies.

Sincerely,

Dr. J.-P. Biberian
(*Chief Editor*)
May 2020

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Research Article

Nuclear Signature in LENR Gas Loading Experiments

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Abstract

Several types of experiments on LENR anomalies were performed at the ARGAL laboratory in Bareggio, in particular using thin films of palladium in H_2 or D_2 atmosphere at various pressures. The laboratory is equipped with instrumentation suitable for the detection of neutrons and gamma emission, with an He^3 detector, and a multichannel detector with a 3-inch NaI crystal. All the experiments carried out have been monitored with these instruments, and in many cases we have found neutron emissions attributable to nuclear events inside the reactor. Some anomalous events were short-lived; others were prolonged for several minutes. Apart from one particular case, the events were modest. In any case, the evidence found shows once again the nuclear nature of the LENR phenomena, in the past highlighted by clear episodes of nuclear transmutations in similar conditions, where it was possible to analyze the material with the appropriate techniques at the end of the experiment.

Keywords: Neutron burst, Nickel foam, Pd electroplating, Pd loading, Transmutations

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1. Introduction

The ARGAL laboratory in Bareggio is equipped with several reactors used to perform experiments on LENR anomalies [1]. The configuration used in the experiments described here is depicted in Fig. 1.

The laboratory is continuously monitored with a He^3 neutron detector (Ludlum) and with a multichannel detector (Ludlum) with a 3" sodium iodide scintillator for gamma radiation, which are placed nearby the reactors.

The Ludlum 12-4 neutron meter detector (Fig. 2) is particularly well suited for neutron monitoring. This detector is interfaced to a PC that uses LabView to record the events reported by the detector. The acquisition program records the data in two different modes, one in the form of events (counts) as a function of time (Fig. 3), indicating the number of counts every minute (left axis) and every hour (right axis); and in a different screen (Fig. 4) in a normalized histogram for counts every hour. The program performs an acquisition over 8000 min, followed by a reset and the beginning of a new acquisition. The data for each complete acquisition are stored in a remote hard disk for subsequent analysis.

Figures 2–4 respectively show an example of a graph for a partial acquisition, an example of an almost complete acquisition and a histogram of an almost complete acquisition.

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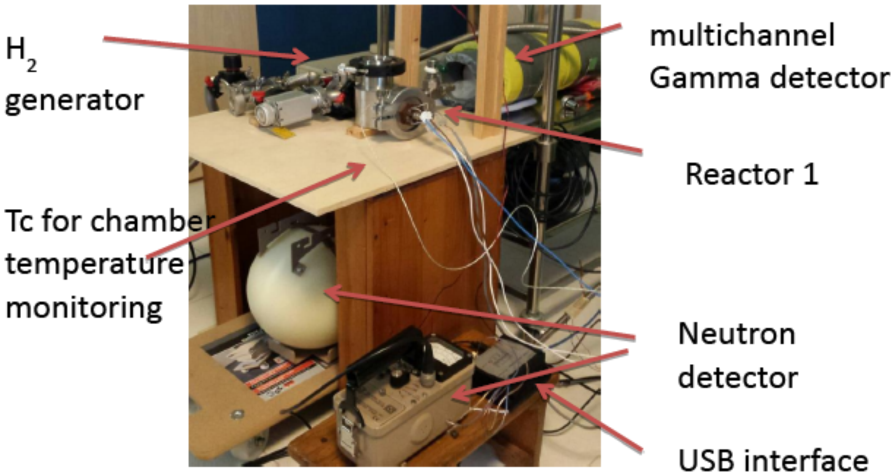

Figure 1. Configuration setup.

2. How to Read the Neutron Acquisition Graph

Figures 2 and 3 show the evolution over time of the pulses coming from the neutron detector. On the X-axis the time expressed in minutes (*bottom*) and in hours (*top*). The left Y-axis shows the neutrons in every single minute (*black points*), which for the most part are on the line $Y = 0$, with some at $Y = 1$, and relatively few for $Y = 2$; $Y = 3$ is a very rare event. The right Y-axis shows neutrons for single hour (green dots linked together by green lines). Each acquisition has a duration of about 8000 min, after which the graph is reset and a new acquisition starts. This happens for 24 h a day, every day of the year, except for a few days break for maintenance of the laboratory or other special needs.

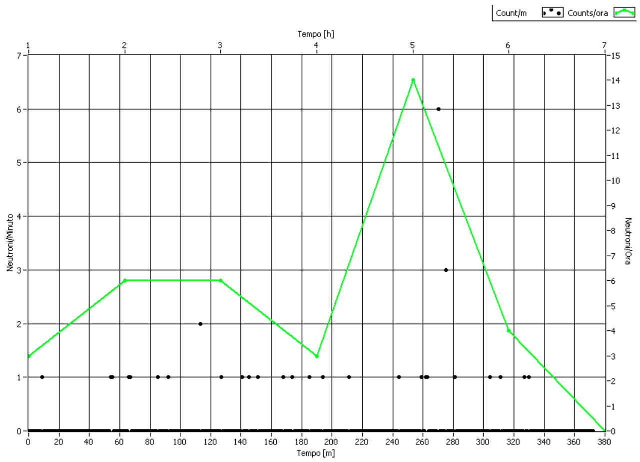

Figure 2. Evolution of the neutron count over 350 min during the experiment.

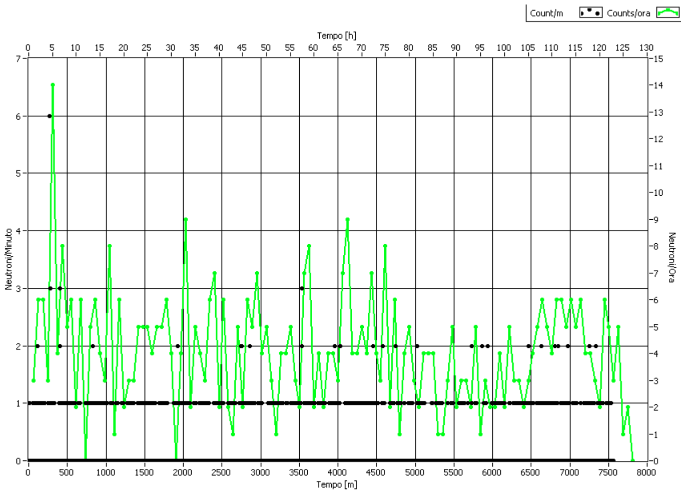

Figure 3. Changes in the neutron count included the above chart (Fig. 2), extended up to 7600 min. This also includes monitoring while trying to reproduce the neutron burst of six neutrons in 1 min, which took place around minute 270. This event is more clearly shown in Fig. 2.

In addition to neutron monitoring, to follow the course of the experiments in a complete and effective way, another PC runs a LabView program acquiring other parameters such as: the temperature of the sample inside the reactor, the pressure in the reactor, the environment temperature, the external temperature of the reactor, possible power to heat the sample and finally the value of a thin film resistance in palladium to monitor the absorption of hydrogen, when the material under test contains palladium. A typical behavior of the monitor resistance is shown in Fig. 5.

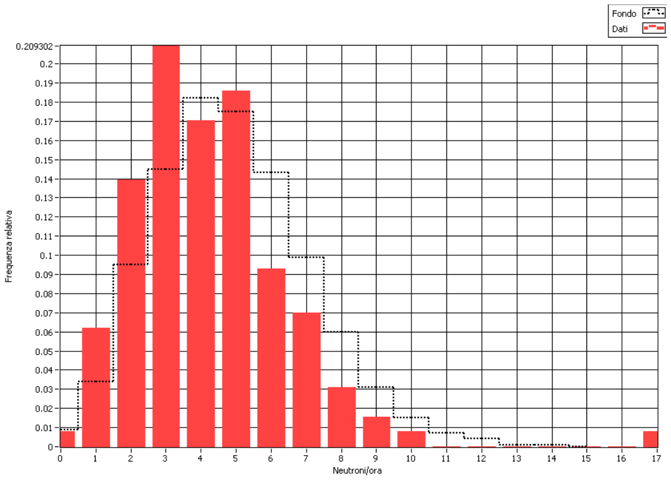

Figure 4. Histogram of the neutron count / hour for a time interval during which an experiment with Reactor 1 containing a sample with a film of palladium in hydrogen at a pressure of 1 bar showed abnormal emission of neutrons while hydrogen was admitted into the reactor (screenshot on 01 December 2014).

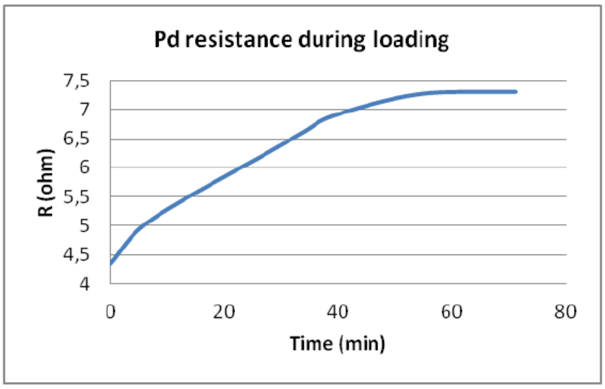

Figure 5. Trend of Pd resistance as the reactor finishes filling with hydrogen at 1 bar pressure. The graph shows the rise in resistance when the palladium was loaded for the first time. During subsequent loadings the change in resistance is faster.

3. Neutron Bursts

As can be seen in Fig. 2, around minute 270 a count of six neutrons was recorded. That is completely anomalous, as we shall see below with a statistical analysis of the performance of this type of monitoring. It is important to note that the abnormal recording of six counts in 1 min coincided with the completion of the absorption, measured by palladium resistance (the resistance value was 7.31 Ω) and that this particular palladium film was being subjected to absorption for the first time.

In the past the same abnormal emission of neutrons was recorded under practically identical conditions, using a different sample with the same structure: 250 nm of palladium on an oxidized silicon substrate. This first episode was not analyzed as closely as the current one, because it was totally isolated and unexpected, and therefore considered to be a result of the statistical fluctuation of the neutron background detection. In any case, we did suspect that an anomaly may have occurred, and we recorded it as histogram trend of neutrons (which is a cumulative figure), stored at that time (Fig. 4). Unfortunately, the graph as that of Fig. 3 was not stored by a screenshot, but it has been recovered as raw data from the external hard disk where all the acquisition data are archived. The Excel graph of this data is shown in Fig. 6.

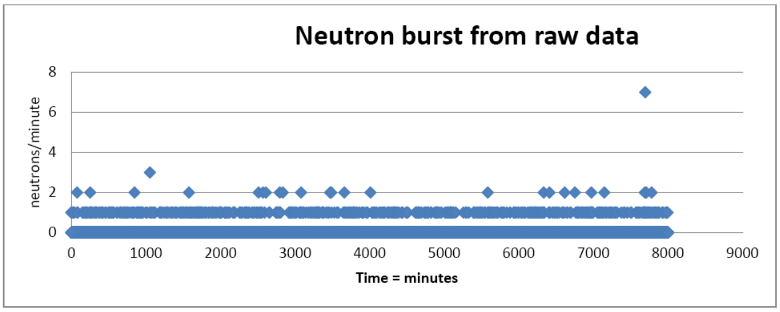

Figure 6. Neutron burst reconstruction from raw data stored on 01 December 2014. The neutron emission of seven neutrons in 1 min was in coincidence with hydrogen admitted into the reactor when the resistance of the palladium monitor resistance was rising.

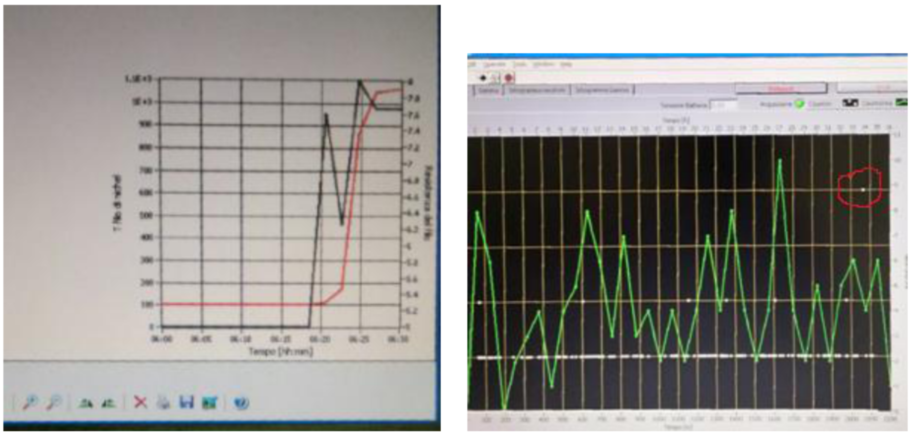

Figure 7. Anomalous neutron burst in coincidence with palladium thin film hydrogen loading (red curve on the left image).

4. Statistical Analysis

To confirm whether signals coming from the reactor are due to internal nuclear reactions, it is necessary to make a statistical analysis. So, referring to real data from a background neutrons acquisition (similar to that of Figs. 2 and 3, but without abnormalities), the events per minute for an interval of 171 min were collected. Subsequently, events over a time interval of 1470 min were collected.

In Table 1, columns 2–4 show such data in the following format: The first row indicates the events per minute that in the specific case are either zero, or 1, or 2, the second row the number of events for the three cases (0, 1, 2) for 171 min and the third row, the number of events for the three cases (0, 1, 2) for 1470 min.

In column 4 the statistic is shown in a normalized form, extending the number of cases up to 6 to determine the likelihood using the Poisson's law, because the events (neutron emissions) are independent from each other [2].

Hence, in columns 8–11 data extrapolated up to six events, as follows: Over 171 min, 10 neutrons were detected. Probability of occurrence: 0.0585 neutron/min. Over 1470 min 91 neutrons were detected. Probability of occurrence: 0.0619 neutron/min.

The two values are quite close. Let us consider $\lambda = 0.06$ n/mn (λ in the Poisson's formula). The Poisson's distribution is given by the formula:

$$P(n) = \frac{\lambda^n \, \mathrm{e}^{-\lambda}}{n!}.$$

The last line of the table shows the probabilities according to this law.

Table 1. Real data and probability table.

	Real data			Probability up to six events per minute						
Cases	0	1	2	0	1	2	3	4	5	6
n	161	9	1	0,9415	0,0526	0,0058				
n	1379	86	5	0,9380	0,0585	0,0034				
Poisson				0.9418	0.0565	0.0017	3.4 10^{-5}	5.08 10^{-7}	6.1 10^{-9}	6.1 10^{-11}

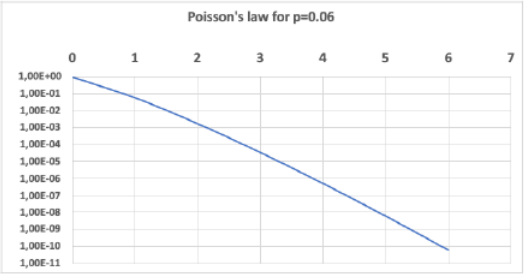

Figure 8. Curve fit for the calculation of the probability for a number “*n*“ of events per minute.

Figure 8 shows the chances of cases actually observed occurring, expressed in exponential form, which we can use estimate the probability of some number of events per minute. For our purposes, this evaluation shows the probability of up to six events per minute; it is equal to 6.1 $\times 10^{-11}$, from which one can derive how often this kind of event should occur on average in the absence of abnormal emissions. The reciprocal of the probability indicates the number of minutes (on average) between one event and the next; for example for the case 1 it would be: 1 / 0.0565 = 17.7 min, which multiplied by 86 (number of events) gives us 1522 min, a value close to 1470 min, that is, the observation interval. Then: $1 / 6.1 \times 10^{-11} = 16 \times 10^{9}$ min between one event and the next in the case of 6 “counts” in a minute, corresponding to 30 441 years. This allows us to state that the coincidence between the loading of palladium films and counting six neutrons in 1 min is an extremely unlikely event, and it is almost certainly an indication of a brief, real nuclear event inside the reactor.

14 May 2018 Neutron Burst: Event Probability 5.08×10^{-7}

5. Monitoring Neutrons with Palladium Inside the Reactor

With a sample of nickel foam on which a thin layer of palladium was deposited, tests were carried out to verify on a small scale what was reported by Mizuno with his experiments in which the samples had similar structures (nickel mesh with palladium deposited by rubbing) [3]. The thermal anomalies found by Mizuno were not confirmed, but clear neutron emission episodes were observed as described above, both in hydrogen than in deuterium. The photos in Fig. 9 show the material and the simple set-up for the palladium electroplating.

Figure 9. Nickel foam, beaker with platinum electrodes and palladium chloride solution for plating.

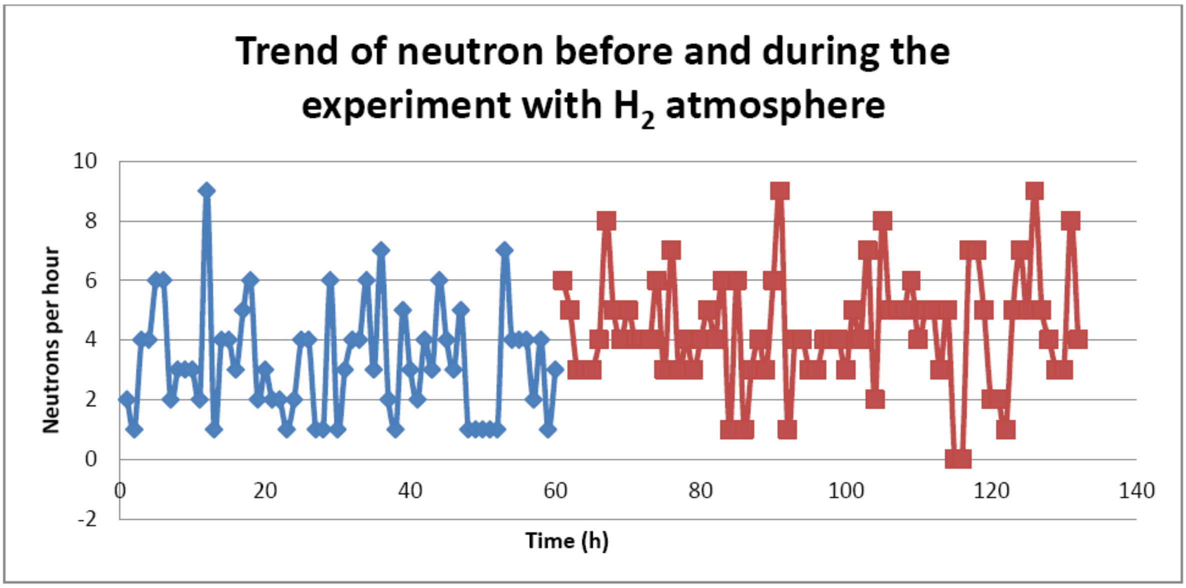

Figure 10. Neutron data with no sample in the reactor (*blue*), and with the sample under test (*red*) in hydrogen atmosphere.

Figure 10 and the followings show that slight neutron emission activity is detected when palladium is present in the reactor, both in hydrogen and deuterium atmosphere. The events that manifest themselves as bursts are instead relatively rare because in almost all cases the palladium inside the reactor was exposed to the atmosphere of hydrogen or deuterium for the first time. That was unexpected. Attempts to replicate these bursts were made immediately after each burst, but they have not produced emissions in the same form.

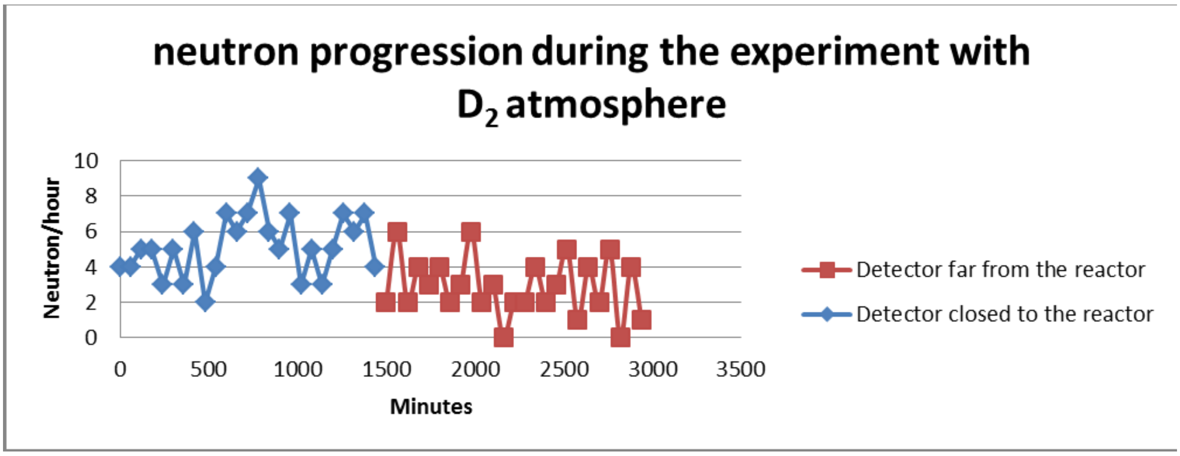

Figure 11. Another example of neutron emission in deuterium atmosphere moving the detector far from the reactor (*red*) and near the reactor (*blue*).

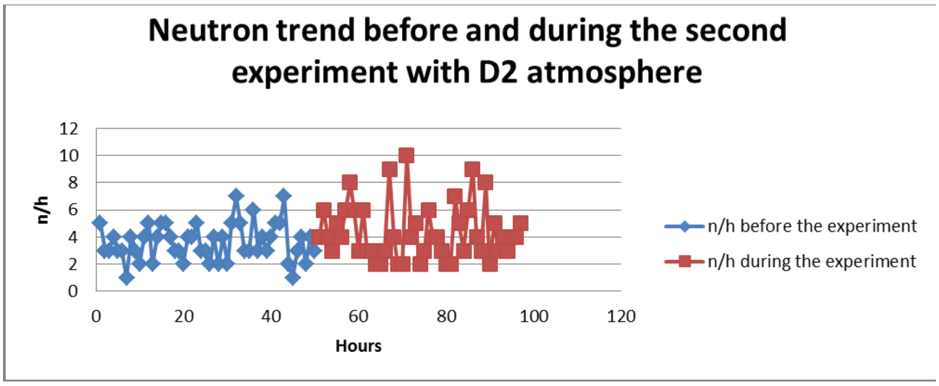

Figure 12. Neutron data with no sample in the reactor (*blue*), and with the sample under test (*red*) in deuterium atmosphere.

In the below histogram a double peak is clearly visible. This is the best sign that two different phenomena are at play. Most events are distributed almost like the background (peak=5). Some events produce a larger number of neutrons and build up an additional distribution (peak=10). Even though this is a short period of measurement with a statistically small amount of data, it confirms that bursts are taking place.

6. Massive Neutron Emission

An event with a significant neutron emission from reactor 1 was recorded in October 2014 (see Fig. 14). The continuously active monitoring system signaled a first burst lasting 3 min when the reactor was under vacuum after a thin film palladium sample irradiated with a 405 nm wavelength laser for 2 weeks was extracted from the reactor. It is important to consider that because palladium film is very reflective, the laser beam had also irradiated the internal walls of the stainless steel reactor. After a first neutron burst lasting 3 min, a few hours later, a more intense and longer second burst (17 min) was recorded. The causes of these anomalous emissions have been attributed to the desorption of the hydrogen gas from the internal walls of the reactor [4]. The reactor was at ambient temperature.

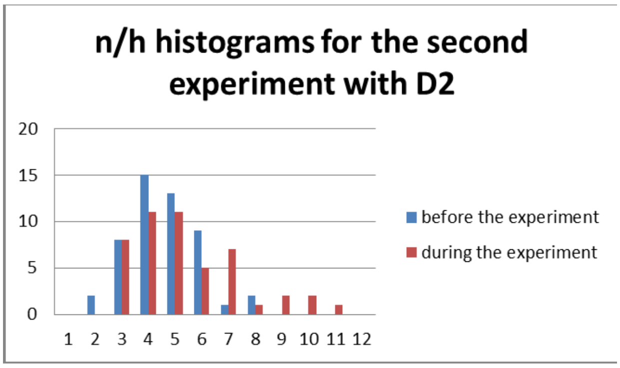

Figure 13. Histogram of the data in Fig. 12.

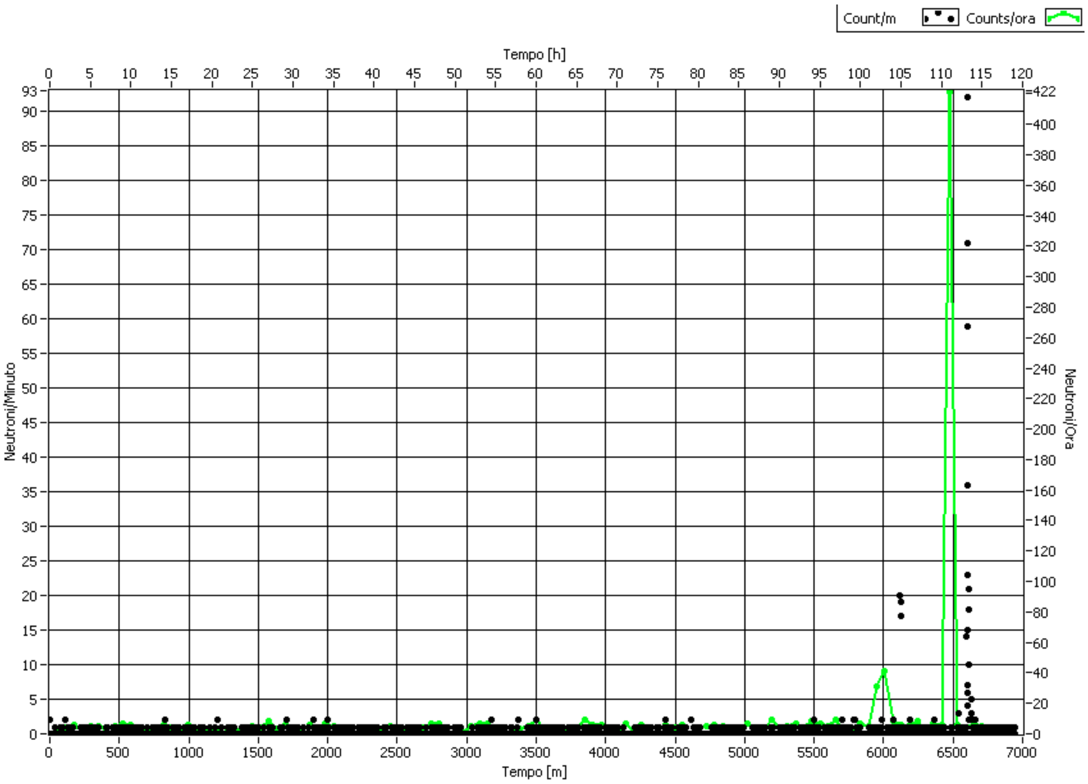

Figure 14. Screen shot of the neutron monitoring PC showing a massive neutron emission from reactor 1 after the experiment with a 405 nm laser.

6.1. Figure 14 Chart description

Figure 14 shows a chart extracted with a screen shot on 18 October 2014 at 4:05 PM.

The first burst occurred about 12 h before the screen shot and the second peak 5 or 6 h earlier.

The duration of the first burst (*black points*) was about 3 min, while the second burst, much more intense, lasted about 17 min.

The green line indicates the neutron average in 1 h, the black dots the neutrons every minute.

7. Conclusions

Abnormal neutron emissions from reactor 1 at the Bareggio ARGAL laboratory were detected several times. Unfortunately, in the most noticeable cases, we do not have a convincing explanation of the mechanism that produced them. Meticulous attempts to replicate the conditions that originally appeared suitable have produced no breakthrough. The current analysis of abnormal emission during the loading of a thin layer of palladium is not based on a mechanism or model, but instead on replication of an event already seen and reproduced in identical conditions. For this reason it is believed that the events are not random, and so the overall experimental outcome confirms that the interaction between palladium and hydrogen is actually the location where nuclear abnormalities of LENR type occur [5]. It cannot be ruled out that other metals in similar conditions also produce anomalous nuclear events.

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Research Article

Is the Nuclear Active Environment a Metals–Silicon–Boron–D_2 Alloy Enabling a Three-body Recombination between Deuteron and the Nuclei of D_2?

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Abstract

The Nuclear Active Environment (NAE) could be a site where three deuterons interact, e.g. a D_2 molecule and a deuteron, where the deuteron is pushed in between the two D nuclei, and form a hypothetical Efimov-like triple D state. Three-boson (Efimov) interactions can have a longer range than two-boson interactions. Two nuclei fuse to helium and the third is ejected in a three body recombination. In rare cases the result is tritium and helium-3. The NAE might be a semiconductor like silicon, known to incorporate hydrogen molecules. The NAE could perhaps be a compound like MoS_2, known as a possible substitute for platinum in electrolytic hydrogen evolution. The NAE might also be an alloy of metals with boron and silicon allowing occlusion of D_2 molecules sitting in a tight vice in a narrow lattice. Or the NAE might be palladium oxide/nickel oxide, which are hydrogenating catalysts. Or it might be a chemical compound such as silicon boride and titanium carbide where D_2 could sit in vacancies. A triple D might interact with lattice atoms according to the scheme ${}^{\mathrm{m}}\mathrm{Me}_{\mathrm{n}} + (3\mathrm{D}) \rightarrow {}^{\mathrm{m}+2}\mathrm{Me}_{\mathrm{n}+1} + \mathrm{He}$, which might lead to the formation of radioactive isotopes.

Keywords: D_2 molecules in solids, Efimov effect, NAE characteristics, Three body recombination, Trapped D_2 molecules

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1. Introduction

Electrolytic low energy nuclear reactions usually happen after a long delay, and with quite low reproducibility [1,2] although palladium/deuterium co-deposition may be a possible exception [3]. Some batches of palladium work, others do not [4]. During the long delay before LENR there are often substantial changes at the surface of the palladium electrode with several elements from impurities or the glass vessel such as silicon [1,2,5]. According to Storms, a nuclear active environment (NAE) must be established for low energy reactions to occur. Little is known about what characterizes the NAE, or what exactly is needed to obtain it [6]. Storms thinks that the NAE are cracks of a particular size allowing fusion and dissipation of energy by soft X-rays [7].

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The products of low energy nuclear reactions are primarily helium-4, much lower levels of tritium, and very low levels of neutrons [1,2]. This is most simply explained by three-body recombination [8–10] (or perhaps multibody [11,12]) among three deuterons, where two fuse to helium and the energy is converted by ejection of the third deuteron as proposed by Takahashi, according to the scheme:

$$\begin{aligned}\mathrm{D} + \mathrm{D}_2 \rightarrow (3\mathrm{D}) &\rightarrow\ {}^4\mathrm{He} + \mathrm{D}\ \ (23.8\,\mathrm{MeV})\\ &\rightarrow\ {}^3\mathrm{He} + \mathrm{T}\ \ (9.5\,\mathrm{MeV}),\quad \text{rare.}\end{aligned}$$

In experiments with low keV deuteron bombardment on titanium deuteride energetic alphas and protons were observed by the groups of Kasagi and Takahashi [8,9,13]. This should not be possible with standard DD fusion, but it is compatible with triple D fusion models. In a palladium lattice the D atoms are almost 3 Å apart, and they do not easily get close because the positive charges are only lightly shielded by the outer electrons. Atoms in a D_2 molecule are 0.74 Å apart. Measurable fusion between D's requires a distance smaller than 0.2 Å [14]. However, according to Efimov [15] three bosons may interact over a longer distance than two bosons.

Efimov showed that three bosons, interacting resonantly, may form bound states, even if there is no bound state between two of the particles. For example, a helium trimer "molecule" exists but a helium dimer does not. In cases with several Efimov states, the second state is 22.7 times larger than the first, and the third state is 22.7 times larger than the second. The energy decreases with a factor $(22.7)^2$ between consecutive states. The first Efimov states have now been observed in atomic systems at very low temperatures [16,17]; The excited helium trimer is 150 Å large, 50 times the size of many molecules [18]. Usually coulomb repulsion negates the Efimov effect at a longer separation than the Bohr radius of 0.53 Å [18], but nobody knows whether shielding by electrons might modify this, so that virtual, short lived Efinov resonances might form between three deuterons brought close together. One could imagine that a deuteron injected between the deuterons of a lattice-trapped deuterium molecule could form a virtual Efimov-like state, followed by a collapse into ^{4}He and an ejected deuteron. This would require that the deuterium molecule not be able to move away; it must be fixed in a vice in the lattice.

2. Possible Nuclear Active Environments

An educated guess about the nuclear active environment would be a material that can incorporate deuterium molecules [19,20] in a tight lattice vice and at the same time be a good conductor. Deuterium molecules can primarily be found in semiconductors with Pauling-electronegativity close to that of hydrogen [21–23]. Good conductors such as most metals "alloy" hydrogen as single atoms. It may not be an easy thing to combine the two requirements in a single material. One possibility might be metallic glasses, e.g. Nickel–Chromium–Boron–Silicon or Palladium–Boron–Silicon [24,25]. The reason for including boron is that Palladium–Boron alloys tend to give better reproducibility in electrolysis experiments [4]. The reason for including silicon is that it is often found at the surface of electrodes after prolonged electrolysis [1,2]. Both compounds have electronegativities close to that of hydrogen. The metallic glasses solidify in complicated manners, in several different phases, some crystalline, some glasslike. The primary use of these alloys is as brazes for joining advanced materials like rotor blades for gas turbines. There are quite a number of them available as thin foils. The fact that these metallic glasses solidify in different phases may mean that one might have microenvironments with semiconductor character occluding deuterium molecules embedded in a conducting matrix.

Another possibility could be compounds like MoS_2 which should be able to intercalate hydrogen molecules between the layers [26]. MoS_2 is investigated as a possible platinum substitute for hydrogen production by electrolysis [27]. Perhaps deuterium molecules might be too mobile in pure MoS_2, but it might be possible to cross-link the layers with other atoms in order to keep the D_2 molecules in place.

Other possibilities might be palladium or nickel oxides. These compounds are commonly used as hydrogenation/dehydrogenation catalysts, meaning that there are equilibria between atomic and molecular hydrogen at their surface. Kasagi's team observed that low keV D bombardment of deuterium in PdO gave fusion rates many times higher than D bombardment of D_2 gas or TiD [28]. Holmlid observed D–D fusions on an iron-oxide cracking, dehydrogenating catalyst after blowing away the electrons with a super-strong laser pulse [29].

Further possibilities might be conducting ceramics such as silicon boride or the dense lattices of titanium or zirconium combined with boron, carbon, or silicon [30]. Some of these ceramics are used as hardened surfaces on drills. The ceramics are tight lattices but with common vacancies, such as minus C. It is known that titanium-carbide dissolves more hydrogen than pure titanium [31]. The extra hydrogen might be sitting as molecules in the vacancies.

3. Transmutations/radioactivity?

If virtual triple-D states are large enough to "touch" the nuclei of the atoms in the lattice, one might find transmutations according to the scheme: ${}^{\mathrm{m}}\mathrm{Me}_{\mathrm{n}} + (3\mathrm{D}) \rightarrow {}^{\mathrm{m}+2}\mathrm{Me}_{\mathrm{n}+1} + \mathrm{He}$. Or perhaps a lattice atom could be part of an Efimov state: $({}^{\mathrm{m}}\mathrm{Me}_{\mathrm{n}} + 2\mathrm{D}) \rightarrow {}^{\mathrm{m}+2}\mathrm{Me}_{\mathrm{n}+1} + \mathrm{D}$. This would fit with Biberian's finding of silver with a surplus of Ag-107 in one of Pons' palladium cathodes that had produced a great deal of excess heat [32]. The Ag-107 might originate from Pd-105 after capture of a deuteron. If this is a "viable" mechanism, then it should be possible to find radioactive isotopes at the surface of electrodes: Cu-60 from Ni-58, Ag-106 from Pd-104, V-49 from Ti-47, etc. Most of the isotopes mentioned are beta-emitters and have reasonable half-lives. There are numerous other possibilities, but many have either too short or too long half-lives to be easily observed. MoS_2 could be particularly interesting, because the many isotopes of molybdenum might be transmuted into isotopes of technetium, which are all radioactive. Chrome plating in D_2O might yield radioactive manganese.

4. Conclusion

Despite many years of labor, the LENR community still does not have a decisive experiment which can persuade mainstream physics and the public that low energy nuclear reactions are real and may become a useful source of energy. A rule of thumb says that it must be possible to demonstrate the principle in a source of energy in an afternoon in a high school laboratory, otherwise the problems of turning it into a practical energy source become insurmountable. A LENR experiment that could be done in an afternoon and end up with clicks on a Geiger counter is sorely needed. Perhaps it would be possible to find an alloy or chemical compound that could turn into a Nuclear Active Environment surface in a few hours.

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Research Article

Cold Fusion Public Policies: Realizing Benefits and Mitigating Disruptive Impacts

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Abstract

Cold fusion (now widely referred to as low energy nuclear reactions, LENR) has many potential energy benefits for society, but it also has risks of major disruption. Despite being rejected soon after its announcement 30 years ago, LENR has continued to be pursued by researchers worldwide. The continued vitality of the field, and substantial progress in understanding and reproducibility of the phenomenon, have challenged the initial verdict on LENR as non-legitimate science. LENR realization for the benefit of society will be enhanced by the forces of the free market. But government policy changes are needed to realize LENR benefits and deal with its anticipated disruptive impacts. Evidence-based policy making is a rational way to revisit negative policies for research support. Technology assessment is a candidate method for identifying and mitigating LENR's adverse secondary effects. Government agencies and the private sector have the opportunity with LENR to accomplish their missions. As a potential new source of abundant, low-cost, and clean energy, LENR has the possibility of substantially improving the long-term prospects of humankind.

Keywords: Cold fusion policy, Disruptive technology, Evidence-based policymaking, LENR policy, Rational public policies, Technology assessment

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1. Introduction

Cold fusion (now widely referred to as low energy nuclear reactions, LENR) has the potential for immense benefit for society as a cheap, clean, and virtually unlimited source of energy. It would also almost certainly be a highly disruptive technology, at least in the short term, with adverse direct impacts on the existing energy infrastructure and indirect effects on associated components of society. Fortunately, policymaking procedures are available to deal with the "double-edged sword" of LENR.

Rational policies have served the public interest for centuries. Evidence-based Policymaking (EBP) is a rational way to set – or reevaluate – policies for LENR research support to realize its energy benefits. Technology Assessment (TA), a rational method of evaluating and mitigating adverse effects of new technologies on the various components

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of society, may be readily applied to the LENR case. Policies for the benefit of society are essential both for realizing energy from LENR and for dealing proactively with its disruptive secondary impacts.

2. Background

The potential benefits of LENR as a new source of energy were well understood when it was announced by Martin Fleischmann and Stanley Pons in March 1989. Examples of LENR benefits are:

- Virtually unlimited energy source.
- Low cost of materials.
- Environmentally secure (no emissions or effluents).
- No harmful radiation or radioactive waste.
- Deployable in centralized or dispersed configurations.
- Energy source is available everywhere without transport or restriction.
- Reduction of energy-related environmental contamination by replacing fossil fuels.
- Decrease of carbon dioxide emissions and mitigation of global climate change.

Nagel has listed no fewer than 40 potential advantages and impacts of LENR development for thermal and electrical power [1]. In addition to its promise as an energy source, LENR may have another benefit, through elemental transmutation, of dealing with the nuclear waste problem.

2.1. New technologies and society

Governments worldwide adopt policies, laws, and regulations to protect and enhance the public interest [2,3], including policies for developing new technologies. The benefit to society from public support of research has long been recognized. This support is particularly important in the early stages of technology development when research costs may not be justified for private sector investment. Salient historical examples are the Manhattan Project, which brought World War II to an end, and the US space program, where research has yielded many benefits beyond the immediate goals of the program. The public interest is well served by rational policies and methods like EBP.

Governments also protect the public interest by addressing the disruptive impacts of new technologies. These impacts are both direct – on existing market solutions (e.g. current business) – and indirect – on sectors of society closely associated with current infrastructure (e.g. workforces, communities, local governments). These direct and indirect impacts are disruptive to both the private sector and elements of society [4].

Because the social costs of new technologies are normally not included in expenditures for their development, these costs are viewed as "market externalities". Public policies may thus be implemented to intervene in the free market to mitigate the adverse secondary impacts and increase the overall benefit of a new technology. A premier example of such intervention is the suite of laws and regulations put in place to protect and clean up damages to the natural environment by market-driven activities such as industries. Government intervention using methods like TA is often necessary to protect the overall public interest.

The opportunity for government intervention for support of beneficial R&D not qualifying for private sector investment and for mitigating adverse secondary impacts are the result of incomplete alignment of private sector interests and the public welfare, which is referred to as "market failure" [5].

2.2. LENR policy status

Notwithstanding its potential benefits, LENR was rejected by mainstream science within a year or so after the 1989 announcement [6,7]. The processes and events that led to the rejection comprise an outstanding case for the field of sociology of science – the social processes by which science is "done" [8,9]. The boundary work of science – determining what is accepted and what is rejected – is a major component of this sociology [10].

A principal reason that LENR continues to be rejected is the challenge it faces as a new phenomenon. Reliable reproducibility remains elusive, and hypotheses to explain it are not yet converging to an adequate explanation. Experimental observations cannot yet be interpreted in terms that are consistent with the current understanding of nuclear physics.

Unfortunately, in some cases skeptical researchers maintained that LENR does not exist because they did not observe it in their experiments; that is, not observing it means that a phenomenon is not legitimate. However, the failure up to obtain success may actually be the result of not achieving the required experimental conditions [11].

Unlike most rejected scientific claims, LENR research did not die out. Instead, investigations have continued by many researchers at locations around the world. Because of its pariah status [12,13], the field has developed a social science structure outside of mainstream science, including:

- Professional organizations. For example, International Society of Condensed Matter Nuclear Science[a,] and Japan CF-Research Society[b].
- International conferences. For example, International Conferences on LENR (ICCFs)[c]
- Magazines and peer-reviewed professional journals. For example, Infinite Energy[d] and Journal of Condensed Matter Nuclear Science[e]
- Websites and blogs[f]. For example, Cold Fusion Now![g] and New Energy Times[h].

Public policy for support of LENR generally followed the scientific rejection of the field, and public resources became very scarce. And, of course, no policies were pursued for dealing with its secondary impacts. Whether the rejection of LENR was a "proper" instance in the sociology of science, or if the public interest has been served by negative research support policies for the past 30 years, seems now to be almost a moot point. Particularly given the demonstrated vitality of the field and the progress that has occurred, the time has come to reconsider these negative policies. In consideration of the public health benefits of a locally available source of heat for cooking and water purification, a strong case can also be made for an ethical mandate to pursue of LENR.

3. Policies for Realizing Benefits

A large gap has emerged between the promise of CF as an energy source and the policies toward its support for realization of its benefits. EBP is a rational and readily available approach for closing this gap [14].

3.1. Evidence-based policymaking for LENR

EBP has its roots in evidence-based medicine [15,16], whose success led to the method being extended to other areas such as business management [17] and public policymaking [18–20]. EBP can help to guide policy decisions when (as is often the case) the best decision is uncertain. Policymakers often do not have a technical background and may

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[a] https://iscmns.org/.
[b] http://jcfrs.org/indexe.html.
[c] . https://iscmns.org/conferences/.
[d] https://www.infinite-energy.com/index.html.
[e] https://iscmns.org/publications/jcmns/.
[f] CMNS Google Group.
[g] https://coldfusionnow.org/.
[h] http://newenergytimes.com/

be challenged in making complicated science or technology decisions. An evidence-based way to address this issue is to translate scientific evidence into levels of evidence (LOEs) that are used in the legal field [21]. Policy responses can then be developed based on the readily understood LOE and associated probabilities [22]:

- Preponderance of evidence (>50%).
- Clear and convincing evidence (70–90%).
- Beyond a reasonable doubt (>90%).

Assignment of the LOE in the case of LENR decision-making involves uncertainty, but the process of making the assignment adds both clarity and rigor. For the LENR case, a preponderance of the evidence (POE) for LENR reality may be asserted by the research credentials and experience of Dr. Fleischmann (Fellow of the Royal Society in Britain) and Dr. Pons (chemistry department chairman), by the basic findings of their LENR experiments [23,24], and by the early confirmations by other researchers. Four examples of early experiments that confirm excess heat are described by Beaudette [25] – Richard Oriani (1990), Robert Huggins (1990), Melvin Miles (1990), and Michael McKubre (1990–1991).

Clear and convincing evidence (CCE) is indicated by the hundreds of additional confirming experiments by many reputable researchers. For example, Storms conducted a review of reports of LENR for the period 1989 to 2004 and found 319 claims of success based on three signatures of the phenomenon: excess heat (184), elemental transmutation (80), and anomalous radiation (55) [26].

CCE is also supported by Bayesian network analysis of LENR experiments. Cravens and Letts [27] conducted a review of 167 reports (1989–2007) and screened them to 122 "qualified reports" based on use of Fleischmann–Pons type electrolytic cells and several other criteria. Johnson and Melich [28] performed a Bayesian network analysis on eight of the qualified reports recommended by Cravens and Letts and found the likelihood ratio (that LENR is real) over 10. Johnson and Melich then added four more reports from the Cravens and Letts list (total of 12 reports) and found a likelihood ratio over 30.

Grimshaw, with the assistance of Johnson and Letts [29,30], conducted a Bayesian network analysis on the first 10 experiments (six of which were considered successes) listed by Cravens and Letts. The analysis assumed "starting probabilities" (pre-analysis estimated probability that LENR is real) ranging from 0.05 to 0.50. With a starting probability of 0.05, the probability of LENR reality increased to 0.59 after the first 10 experiments. A starting probability of 0.50 (50/50) led to a probability of 0.96 after the 10 experiments. Such high likelihood ratios and probabilities clearly support an LOE at the level of CCE.

CCE is further indicated by the strong interest of large and well-known private sector companies [31,32] that are currently funding the research. The development of prototype devices (e.g., Brillouin's "Controlled Electron Capture Reaction approach[i] and JET Energy's NANOR and PHUSOR devices[j]) that may be producing LENR energy also supports a CCE level.

It seems likely that an LOE of beyond a reasonable doubt (BRD) will have to await publication of a convincing hypothesis based on current (or extension of) understanding of nuclear physics or development of a readily reproducible experiment. Alternatively, BRD may be established upon announcement of a working LENR device such as a water heater or electric power generator.

What are the appropriate LENR policy responses to the levels of the evidence? The answer is again a matter of opinion, but consideration of two relevant scenarios again increases clarity and rigor. The following are proposed as rational responses for a conservative scenario.

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[i] https://brillouinenergy.com/science-technology.

[j] http://world.std.com/~mica/jetenergy.htm.

- POE Reinstate LENR and pursue its development rigorously along with other emerging energy technologies.
- CCE Accelerate LENR research in comparison to competing potential energy sources.
- BRD Institute a crash program to achieve full understanding of LENR and realization of its benefits, perhaps at a level comparable to the Manhattan Project.

For a more liberal scenario and considering the immense potential benefit (and ethical mandate) of LENR, a rational policy response to POE would be to enhance its research in relation to other emerging technologies. A response to CCE (as well as BRD) would be to undertake a crash program for LENR understanding and benefits realization.

3.2. Implementation of policies for realization

EBP-based strategies for LENR research must take into account several considerations:

- Complexity of the chemistry aspects of the phenomenon.
- Accommodation of nuclear physics for LENR observations.
- Interplay of the issues of reproducibility and explanation.
- Location, status, and capabilities of experienced researchers in the field.
- Collection, interpretation, and utilization of experimental results to date.
- Research support in a centralized or dispersed manner.

The chemical conditions required for LENR constitute a large number of variables (“parameter space”) that contributes to inadequate reproducibility of the phenomenon. The inability of current understanding of nuclear physics to account for LENR observations is one of the principal reasons for its early rejection and continuing pariah status. Research strategies must address the interrelated issues of explanation and reproducibility. A satisfactory explanation would lead to improved experiments and enhanced reproducibility, and more reliable reproducibility would lead to greater understanding and development of an adequate theory.

A great deal of information, particularly experimental results, has been generated by many LENR researchers over the past 30 years and may provide a foundation for future research. Similarly, experience and insight gained on other LENR aspects, including research methods and current competing hypotheses, could be a resource for developing research plans and selecting investigators, locations, and facilities. Research strategies could involve dissemination of resources to individual researchers and labs to address various facets of the problem. Alternatively, the research may benefit from a centralized approach (or two or three major locations) to help set priorities, share results, and enhance communication.

4. Policies for Dealing with Disruptive Impacts

Proactive planning for dealing with disruptive technologies like LENR is essential for achieving their overall benefit to society.

4.1. Technology assessment for adverse secondary effects

TA is a policy analysis approach for identifying and mitigating the adverse secondary impacts and unintended consequences of beneficial new technologies on the existing infrastructure and associated elements of society [33–35]. TA was developed in about the same timeframe, generally in the 1970s and 1980s, as the major environmental laws and regulations that were instituted to prevent future pollution and clean up past contamination [36]. Although both are examples of government intervention in the free market to protect the public interest, the scopes of TA and environmental protection are different. In TA, overall society rather than the natural environment is emphasized. And TA's focus is on the adverse impacts of innovative technologies rather than on the impacts of existing market-driven activities (such as manufacturing) on the environment. The TA generally includes the following elements [37,38]:

- Development of the TA team and advisory group.
- Statement of the problem and description of the technology.
- Identification of potential direct and indirect impacts.
- Delineation of affected entities.
- Determination of policy options for dealing with the impacts.
- Description of the policymaking infrastructure and agencies.
- Conclusions and policy recommendations.
- Implementation of selected policies.

The TA team and advisory group include both policy analysis professionals and knowledgeable persons from the entities (private sector and government) most directly involved with or impacted by LENR deployment.

4.2. Implementation of LENR mitigation policies

TA has been applied successfully for energy-related issues previously, for example for broad-based development of energy resources [39] and for coal slurry pipelines [40], and it can be readily applied to the LENR case [41]. A specific procedure based on the above steps is shown below.

4.2.1. *Form project team and advisory group*

Because of the broad range of energy infrastructure and social system impacts, a multidisciplinary team will be required for the TA. Participatory TA [42,43] will be emphasized, which will include both energy technology experts and policy analysis professionals. The team will perform most of the impact analysis and development of mitigation recommendations. The Advisory Group, including private sector and government representatives, will provide senior guidance as the TA is performed.

4.2.2. *Characterize LENR as disruptive technology*

The energy (and perhaps other) technologies that will emerge from LENR will be described in detail to enable assessment of their direct and indirect impacts. Although considerable information is available, reasonable projections of the types of devices, the rates of deployment, and success in energy market penetration will be made.

4.2.3. *Refine methodology for impact assessment and mitigative measures development*

TA has a well-developed basic process that can be applied to specific technologies and social contexts. This methodology will be refined for the LENR case based on the detailed characterization of the preceding step. It will include clear identification of the public and private entities that will be directly or indirectly impacted.

4.2.4. *Delineate direct impacts on energy infrastructure*

Impacts on the components of the full cycle of energy production, transportation, storage, and consumption will be identified. Because LENR is likely to be deployed as both a centralized and dispersed energy source, different components will be affected differently. The rate of deployment and market penetration in the energy sectors will be included in the assessment. As the type, degree, and rate of direct impacts are delineated, mitigation alternatives will be identified.

4.2.5. *Assess indirect impact on social systems*

A large portion of society is closely tied to the current energy infrastructure. The social elements that will be impacted can be determined from the components of the energy infrastructure identified above. Because social systems are likely to have limited ability to discern and deal with emerging disruptive impacts, they may be particularly vulnerable. Proactive planning is therefore particularly important to mitigate the social costs of LENR deployment. Mitigation strategies will be prepared for the various entities having similar types of indirect impacts, such as communities, non-energy businesses, workforces, governments, and financial institutions.

4.2.6. *Prepare integrated mitigation plan*

It is clear that the disruptive impacts of LENR on the energy infrastructure and social systems will be closely related. The mitigative measures developed for the direct and indirect impacts will be reviewed, and a coordinated plan will be prepared to take advantage of efficiencies and avoid measures having cross purposes. The agencies and other entities available to implement mitigative actions will be identified in the plan.

5. Corollary Policy Considerations

Several factors must be taken into account for LENR policymaking to be effective:

- Opportunities for agencies to accomplish their energy-related missions by incorporating LENR in their scope.
- Differences in the agencies involved in supporting research and dealing with adverse impacts.
- Development of mitigation strategies in coordination with research support and LENR realization.
- Integration of planning and implementation among agencies both nationally and worldwide.
- Coordination of policies between the public and private sectors.
- Overcoming inertia of LENR rejection and continuing pariah status.

These factors will be addressed by exploring the opportunities and responsibilities of government agencies and the private sector as well as coordination and integration of their policies.

5.1. Agency opportunities

Policymaking for LENR development and impact mitigation present opportunities for national and international agencies to realize their energy-related missions [44]. Given the importance of LENR realization and dealing with its anticipated impacts, it may reasonably be argued that agencies have strong obligations toward LENR.

The types of agencies and their energy-related missions are quite different for LENR support and for mitigation of adverse impacts. For example, in the U.S. the Departments of Energy and Defense are entities having energy development interests. Examples of government entities having mandates for market intervention for the public interest are the Environmental Protection Agency and the Department of Health and Human Services.

5.2. Role of the private sector

Whereas governments have the twin role of LENR support and impact mitigation, the focus of the private sector is mainly on development. Market force will be essential for realization of LENR benefits, but it may be argued that the market cannot yet be fully engaged. Because of its challenges in reproducibility and adequate explanation, LENR continues to be a high risk for private sector investment. This risk is a principal argument for public support of research in its current early development stage. If the early-stage research is publicly funded, the private sector may then step in for applications and product development. At that point the power of market forces can be engaged to fully realize LENR benefits.

At the same time, it is noted that research is being funded by "angel investors" – not requiring a near-term reasonable rate of return – and (as noted above) by large companies (especially energy consumers) having large resources and a major stake in the success of LENR. A number of startups and other small companies are also pursuing LENR, particularly through empirical efforts to develop useful devices (rather than fundamental research for basic understanding of the phenomenon). Efforts by the private sector to realize the benefits of LENR will be enhanced by updating the current negative stances for intellectual property protection (patents, trademarks) by government entities, particularly in the US patent and Trade office [45].

5.3. Policy integration

Policymaking for dealing with the adverse secondary impacts of LENR energy must be coordinated with policies for its research support and for realization [46]. Timing of mitigation planning should follow the rate of development and anticipated market penetration. Such policy coordination will enhance efficiency and avoid plans having cross purposes. Coordination is also essential among agencies having similar responsibilities – support or mitigation planning – to meet their respective responsibilities (e.g. DOE and DOD, EPA and HHS). Policy coordination is also important among agencies at the international and national level and between the public and private sectors.

5.4. Overcoming inertia of rejection

Policymaking for LENR is strongly affected by its status as a pariah science.

In a sociology of science context of rationality, it may be asserted that the level of evidence of LENR must determine future policies for LENR research and realization as outlined above. However, LENR has a large inertia of negative perception. The importance of overcoming its pariah status cannot be overestimated. It is recognized that despite the advantages of translating scientific evidence into levels of evidence (POE, CCE, BRD) described above, the EBP approach may be constrained by the inertia of LENR's negative perception and continuing pariah status.

If ultimately LENR becomes understood as a new – or extended – branch of nuclear physics (as well as a source of energy), it will almost certainly be recognized as "revolutionary science". Such revolutionary developments that expand the boundaries of scientific knowledge are often initially rejected by mainstream science [47,48].

One scientist, a Nobel Laureate, disagrees with the way in which LENR was not accepted and has referred to the continued rejection as "pathological disbelief" [49].

One possible way of lifting LENR out of rejection is to show that it is science rather that pseudoscience. This approach amounts to asserting that an error occurred in the boundary work of science in the LENR case. An analysis of criteria set forth by three prominent boundary workers (science skeptics) – Irving Langmuir [50], Carl Sagan [51], and Michael Shermer [52,53] – has been performed for LENR [54]. The 27 overlapping criteria of the three skeptics were phrased as questions, and each question was answered for LENR. It was concluded that the criteria were met and that LENR is science, not pseudoscience.

6. Summary

LENR has tremendous potential benefits as a new source of abundant, cheap, and clean energy. But as it becomes widely deployed, it will also have major direct impacts on the energy infrastructure and indirect effects on associated elements of society.

The field was rejected as legitimate science within a year or so after it was announced by Fleischmann and Pons in 1989. Negative public policies for research support soon followed. But the field did not die out after rejection. It has continued to be pursued by researchers at many locations worldwide. Although much progress has been made in the past 30 years, it still has issues of insufficient reproducibility and inadequate understanding.

The time has come to reconsider negative policies toward LENR. Evidence-based policymaking is a rational approach for making decisions for research support in the public interest. Decisions based on the level of evidence will enhance the prospect of realizing LENR benefits. Because it will be a disruptive new technology, public policies are also needed to mitigate LENR's direct and indirect impacts. Technology assessment is a good method for dealing with the secondary impacts of LENR.

Private-sector entities will help LENR benefits to be realized through the impetus of market forces. Government intervention in the free market for supporting new beneficial technologies and for mitigating their disruptive impacts is also essential for the public welfare. Many agencies have a mission to develop new sources of energy. Others have a mandate to protect the public from adverse secondary impacts. Both types of agencies have the opportunity to help accomplish their missions by including LENR.

Policies for impact mitigation must be coordinated with support policies for efficiency and to avoid cross purposes. Similarly, integration of policies among agencies – and between the public and private sector – is essential for the public interest. Regardless of whether policy is guided by the level of evidence, or the need for proactive planning for impact mitigation, LENR will continue to have challenges in emerging from its long-standing rejection and continuing pariah status.

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