

**Evidence of Operability and Utility from  
Low Energy Nuclear Reaction Experiments**

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## Abstract

An objective of this report is to remove doubt about measured results from Low Energy Nuclear Reaction (LENR) experiments, even though the mechanisms that produce LENR are not fully understood. The report demonstrates that there is much reputable evidence in available technical records, which shows LENR devices are capable of producing energy. *It has been demonstrated experimentally and often that chemical energies can produce nuclear reactions.* Significant energy gains are possible. The “excess heat” found by Fleischmann and Pons has attractive features. They include low levels of prompt and residual radiation, and no production of green house gases. Reaction by-products, such as tritium or helium, are also generated. They can only result from nuclear reactions. Low Energy Nuclear Reactions have great practical potential.

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# Evidence of Operability and Utility from Low Energy Nuclear Reaction Experiments

David J. Nagel  
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## 1. Introduction

Martin Fleischmann and Stanley Pons announced in 1989 the discovery of “cold fusion”, that is, the production of heat in electrolytic cells containing deuterium oxide and palladium<sup>1</sup>. The announcement became extremely controversial for two reasons: (a) it disagreed with accepted theory, and (b) other scientists could not quickly reproduce their results. Since that time, however, many positive results from both similar and diverse laboratory experiments have demonstrated that heat and nuclear reaction products were produced in Low Energy Nuclear Reaction (LENR<sup>2</sup>) experiments. This report has been written to present and discuss some of the experimental results and, thereby, remove doubt that the reader might have regarding the existence of LENR, their operability and their utility. Operability is demonstrated when a LENR device produces heat or nuclear reaction products. Utility of an "operable" LENR device is demonstrated when its design is subsequently used in the design of another "operable" LENR device. Energy produced by LENR portends game-changing utility.

The report is based on some of the many positive laboratory results over the intervening years since 1989. There is reputable evidence in many readily available technical records that LENR devices are capable of producing energy. That is, LENR have been achieved. It is shown that the heating technique found by Fleischmann and Pons has several attractive features, especially compared to current fission reactors and hypothetical hot fusion reactors, as well as fossil fuels. Further, LENR by-products, such as tritium and helium, have been produced. Overall, this report shows that, though a new area of technology, LENR are operable and have great potential utility.

The story of LENR is an evolving chapter in the history of science. Regarding its operability, the situation is somewhat similar to that for superconductivity between its discovery in 1911 and its understanding about 40 years later. That lack of understanding did not negate the experimental reality of superconductivity. Similarly, our current imperfect understanding of the mechanisms behind LENR does not invalidate the large and strong experimental data base for the existence and characteristics of LENR. Much is known empirically.

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<sup>1</sup> M. Fleischmann and S. Pons, “Electrochemically Induced Nuclear Fusion of Deuterium”, J. Electroanalytical Chemistry, Vol. 261, pp. 261-267 (1989) and Errata in Vol. 263.

<sup>2</sup> LENR can be read as either singular (“reaction”) or plural (“reactions”), and is used both ways in this report.

With regard to LENR utility, the situation is similar to that for the transistor in the late 1940s. Then, transistors were already shown to work, so they were operable. Devices produced to demonstrate that fact were already useful or had great potential utility. Transistors were envisioned to become smaller and more reliable than vacuum tubes. They had promise of very significant utility. Similarly, LENR are now well established experimentally with operable devices. The systems developed to investigate LENR have utility. And, energy generators of the future are envisioned to be compact due to high energy density of LENR, and also cost-effective compared to the burning of fossil fuels. A large amount of development work over many years will be needed to realize the full commercial promise of LENR, as it was for the transistor.

Fleischmann and Pons used the term “nuclear fusion” when this field of research was initiated in the mid-1980s, because the amount of energy output that they measured was greater than could be accounted for by chemical reactions. They knew that the probability of conventional deuterium (D) fusion at room temperature is miniscule. In “hot fusion” or “thermonuclear fusion”, deuterons in a plasma with a temperature of hundreds of millions of degrees move at very high speeds. The inevitable D-D collisions occur at sufficiently high kinetic energies to overcome electrostatic repulsion between their like positive charges, leading to nuclear contact and what are called fusion reactions.

Both chemical and nuclear reactions commonly cause two types of effects, products and energy. Reaction products from conventional, collisional, “hot”, “thermonuclear,” D-D fusion are shown in Table 1. The energy carried off by the particles in the two most probable reaction pathways is manifested as kinetic energy of those particles. True “fusion” only occurs in the third branch. Helium-4 is produced with a small recoil energy and emission of a gamma ray with 23.8 MeV.

Table 1. D-D Hot Fusion Products<sup>3,4</sup>.

| <b>Products</b>        | <b>Energy</b> | <b>Probability</b> |
|------------------------|---------------|--------------------|
| Tritium and Proton     | 4.03 MeV      | 50%                |
| Helium-3 and Neutron   | 3.27 MeV      | 50%                |
| Helium-4 and Gamma Ray | 23.85 MeV     | 10 <sup>-7</sup>   |

LENR experimenters in the early 1990s naturally sought to measure the products listed in Table 1. Protons are ubiquitous, so they were not measured. However, tritium, neutrons, helium-3, helium-4 and gamma rays are all measurable. So, numerous scientists sought to detect and quantify those D-D fusion products. The early work showed that the reaction probabilities were very unlike those for conventional D-D hot fusion. So, we have known for over a quarter of a century that conventional D-D fusion does not occur in LENR experiments. Two features, the

<sup>3</sup> <http://iopscience.iop.org/article/10.1088/0029-5515/45/10A/001>.

<sup>4</sup> [arxiv.org/pdf/astro-ph/0211258](http://arxiv.org/pdf/astro-ph/0211258).

unusual ratio of tritium atoms to neutrons and the absence of easily-measurable gamma rays, are solidly established by numerous experiments. Scientists and engineers, who have sought to measure LENR-produced energy, repeatedly found striking results. Levels of energy production far beyond what can be explained by chemistry were accurately measured. The remarkable results were due to high energy gains (i.e., the ratio of the energy from a LENR system to the energy needed to produce such reactions). Output thermal energy in excess of the electrical input energy is termed “excess energy” or “excess heat”<sup>5</sup>. That is the energy ascribed to LENR.

This report has three introductory sections (2-4) and four main sections with experimental results (5-8). Sections 2 and 3 discuss the basics of LENR experiments and availability of LENR information. Section 4 reviews the technologies for making power and energy measurements. Such measurements are not widely discussed in physics, which is part of the reason relatively few people accept data from them. Then, Section 5 summarizes key data on the production of heat from LENR experiments. Evidence is presented for generation of heat at levels far beyond what can be explained chemically. Primary attention is given to several papers that report strong heat production. But, other papers and effects are mentioned. The appearance (production) of tritium, helium and other elements in LENR experiments is detailed in Sections 6-8. Several papers are noted and discussed for each of those nuclear products.

Various criteria were used for choosing the papers highlighted in this report. They include early papers, and papers with very strong data, where the authors had good records, adequate equipment and proper procedures. Other reviewers might choose different papers from the vast body of literature on LENR. But, the information offered in this report ought to be sufficient to make the case for operability and utility of LENR. The fact that reproducibility and controllability of LENR experiments are still imperfect, probably due to some unknown materials factor, does not obviate the cases for both operability and utility. The appendices list key references that can be used by personnel with responsibilities for assessing the status and promise of LENR. Appendix D provides a link to dozens of refereed papers from one laboratory.

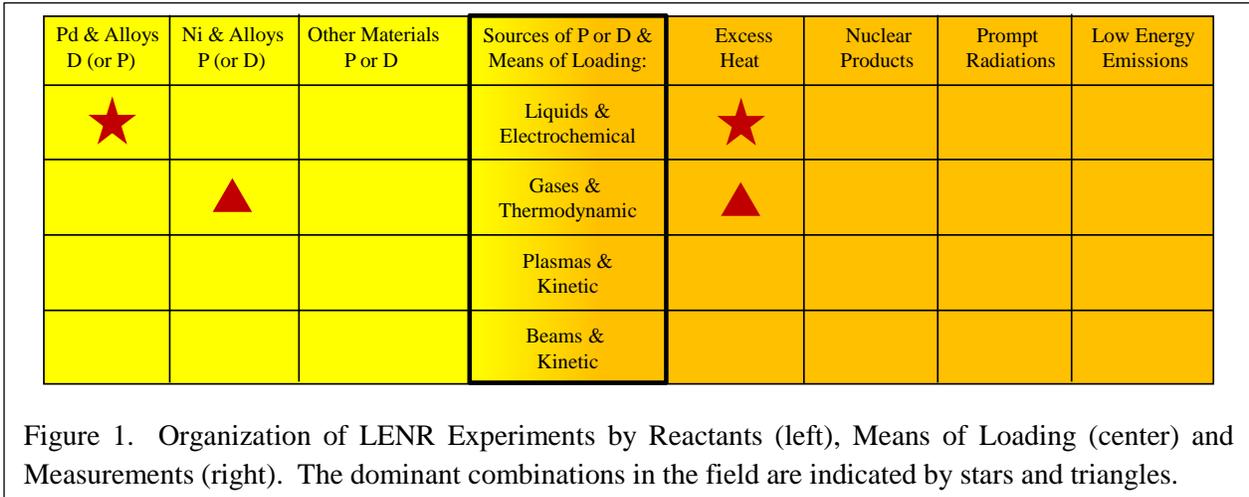
This report is not comprehensive in areas covered, nor in the coverage of the chosen areas. There are many other papers, reports and resources about LENR, which could have been included. Several of the works that are reviewed provide vectors to these other LENR resources. They and other references, which are provided, can be used for further assessment of LENR status and utility. It is desirable to focus on the early papers about any topic within the LENR field for three reasons. Scientific credit is of one of them, but that is of less interest in this report. Another reason, very germane to the case for the operability and utility of LENR, is to demonstrate that much strong information was available early in the field, that is, in the first half of the 1990s. Finally, citation searches based on such early papers provide a fast way to learn about later developments, many of which are important.

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<sup>5</sup> C. G. Beaudette, “Excess Heat”, Oak Grove Press, 2<sup>nd</sup> Edition (2002).

## 2. Overview of LENR Experiments and Results

Many kinds of LENR experiments have been performed during the last 28 years since the Fleischmann-Pons announcement. The diversity of materials, two isotopes of hydrogen, many means of bringing the materials together, and numerous types of measurements can make it difficult to achieve the orientation needed to understand what was done and found, and the resulting bases for operability and utility. A means to put all of the wide variety of what has been accomplished in perspective is offered by the simple matrices in Figure 1. The box in the center with the heavy outline shows the source of the protons (P) or deuterons (D) and the means (called loading) of bringing them into contact with metallic materials: electrochemical loading from liquids; thermodynamic loading from gases; kinetic loading from plasmas; and, kinetic loading from ion beams. It must be noted that low energy plasmas and beams, which produce kinetic loading, do not directly cause any nuclear reactions. They only prepare conditions under which LENR can occur by putting P or D into intimate contact with metals.



Information on the left of Figure 1 in yellow shows the materials employed in LENR experiments and the isotopes of hydrogen used with them. Pd and its alloys have been most studied with deuterons from heavy water, because that was the system used by Fleischmann and Pons since about 1985. Nickel and its alloys have been widely studied with protons from hydrogen gas since the early 1990s. A wide variety of other materials, notably titanium, has also been studied experimentally with both protons and deuterons.

Information on the right of Figure 1 in orange gives the types of measurements made in LENR experiments. They include: measurement of “excess heat” (i.e., output thermal energy minus the input electrical energy); the detection or quantification of nuclear products from the reactions; measurement of prompt radiation (such as fast ions or neutrons); and, measurement of various low energy effects, including infrared and acoustic emissions. The numbers of experiments reported for each of the boxes in Figure 1 vary widely. The stars and triangles in Figure 1

indicate the two cases that have been most studied experimentally since the beginning of the field. But, many other combinations have also been explored and have yielded important data.

*The single most important feature to emerge from all the types of experiments over the decades is the ability to induce nuclear reactions by using chemical energies.* Nuclear reactions generate energies in the range of MeV, while the energy scale for chemical reactions is eV. So, if about one million eV can be released with one eV, there is the possibility of energy gains of one million. It is far from proven that one chemical reaction will produce one nuclear reaction, and statistical considerations make it unlikely that gains of  $10^6$  can be realized. Still, prospects for significant energy gains from LENR generators are very good.

The International Tokamak Experimental Reactor (ITER) <sup>6</sup>, being built in France, is aiming for a gain of 10. That one hot fusion facility is costing well over \$20B and will require over 20 years to complete and test. By comparison, gains much greater than 10 have been achieved during LENR experiments. They are summarized in a recent article<sup>7</sup>. The most reliable reported LENR gains are less than 10. A gain of 26 that has been documented (but not reproduced) is discussed in Section 5 below. The highest published LENR gain was estimated to be about 800, but has not been independently verified or reproduced<sup>8</sup>. This uncertainty over the gain should not mask the fact that large LENR gains have been reported by competent and well-equipped scientists. Commercialization of high gains would make the production of electricity and other uses of thermal power dramatically cheaper than burning of fossil fuels or other current technologies.

The fact that the precise mechanism(s) behind LENR are imperfectly understood does not invalidate or even decrease the strength or quality of the experimental data that can only be interpreted as evidence of nuclear reactions induced in low energy (temperature) experiments. Supernova 1987A was a natural phenomenon that was not reproducible or controllable, but it was real<sup>9</sup>. Even though LENR experiments are man-made, and not fully reproducible or controllable, the same reality applies to them. Data from them cannot be dismissed any more than the data from SN 1987A can be disregarded. This assertion is independent of the current ignorance of LENR results by most individuals in the mainstream scientific community.

The immense difference between LENR and the types of fossil energy currently in use is the possibility that LENR will contribute clean energy solutions for our planet. This is important, given both the increasing global population and increasing *per capita* energy use, as poorer countries continue to develop. Information about LENR should be known much more widely.

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<sup>6</sup> <https://www.iter.org/>.

<sup>7</sup> D. J. Nagel, "Energy Gains from Lattice Enabled Nuclear Reactions", *Current Science*, vol. 108, pp. 641-645 (2015).

<sup>8</sup> T. Mizuno and Y. Toriyabe, "Anomalous Energy Generation during Conventional Electrolysis", in *Proceedings of the 12<sup>th</sup> Int'l Conference on Cold Fusion*, A. Takahashi, K.-O. Ota, and Y. Iwamura (Editors) World Scientific, pp. 65-74 (2006).

<sup>9</sup> [https://en.wikipedia.org/wiki/SN\\_1987A](https://en.wikipedia.org/wiki/SN_1987A).

### 3. Information about and from LENR Experiments

The very large amount of available LENR information is an important consideration for the discussion of experiments. It is possible to categorize LENR experiments by how the reactants are brought together and what measurements are made, as in Figure 1. Another useful way to organize information in the field is to consider the two major types of experiments and the two primary material systems, as illustrated in Table 2. In general, the Pd-D system has been studied most by using electrochemical loading, and experiments with the Ni-H system have generally been performed with gas loading.

Table 2. Major Types of LENR Experiments.

| Experimental Method  | Palladium and Deuterium                 | Nickel and Protium                        |
|----------------------|---|---|
| Electrolytic Loading | Original Method of Fleischmann and Pons | About 20 Groups Early in the Field        |
| Gas Loading          | Few Papers, mainly from Arata and Zhang | Piantelli, Focardi, Rossi and Many Others |

The International Conferences on Condensed Matter Nuclear Science have been a primary global forum for the field over the decades since Fleischmann and Pons announced their ability to produce excess heat energy. The meetings were initially known as the International Conference on Cold Fusion, with the abbreviation of ICCF, which has been retained. The primary topic of the field came to be called Low Energy Nuclear Reactions (LENR), although there are about twenty other names for the subject<sup>10</sup>. Links to the proceedings of many of the ICCFs are on the web<sup>11</sup>. Proceedings of the recent ICCF conferences are published by the Journal of Condensed Matter Nuclear Science<sup>12</sup>. Proceedings of the annual meetings of the Japan Cold Fusion Research Society are on line<sup>13</sup>. Information on many of the twelve International Workshops on Anomalies in Hydrogen Loaded Metals is also on the internet<sup>14</sup>. The 23<sup>rd</sup> Russian Conference on Cold Nuclear Transmutations and Ball Lightning was held in June of 2016.

Several web sites are devoted to presenting information on LENR. One has a library with thousands of articles, many of which can be downloaded<sup>15</sup>. There have been months when the average rate of *downloading* papers from that site was about one per minute. A 2009 tally of papers by Rothwell, the keeper of the web site, is available<sup>16</sup>. There have been over four million downloads of LENR papers from that one web site. Many papers are available from the

<sup>10</sup> D. J. Nagel, "Scientific and Commercial Overview of ICCF-18—Part 2", Infinite Energy magazine, Issue 113, pp. 9-21 (2014).

<sup>11</sup> <http://newenergytimes.com/v2/conferences/LENRConferenceProceedings.shtml>.

<sup>12</sup> <https://www.iscmns.org/CMNS/publications.htm>.

<sup>13</sup> [http://jcfirs.org/proc\\_jcf.html](http://jcfirs.org/proc_jcf.html).

<sup>14</sup> <https://www.iscmns.org/search.htm> and <https://www.iscmns.org/work12/index.htm>

<sup>15</sup> [lenr.org](http://lenr.org) or [lenr-canr.org](http://lenr-canr.org).

<sup>16</sup> J. Rothwell, "Tally of Cold Fusion Papers" (2009). Go to [LENR-CANR.org](http://LENR-CANR.org) and search with "tally".

International Society for Condensed Matter Nuclear Science<sup>17</sup>. Other web sites are also useful resources on LENR, including the New Energy Foundation<sup>18</sup>, the New Energy Times<sup>19</sup>, Cold Fusion Times<sup>20</sup> and Cold Fusion Now<sup>21</sup>. Note that some sites, and even current papers, continue to use the original name of the field, that is, “cold fusion”. Whatever the terminology, a large amount of experimental literature is available, and is open to discussion and criticism. There should be no excuse, by those with relevant responsibilities for energy production, transport, storage and use, for being unfamiliar with the LENR literature.

#### **4. Power and Energy Measurement Technologies**

We now turn to the technologies that are employed to measure quantitatively power due to LENR. The published experimental data on production of energy by LENR was obtained with many types of electrical instruments, especially calorimeters. The character and performance of the instruments are fundamental to understanding reported LENR energy production. Measurement methods are reviewed below before turning in the next section to the actual evidence for LENR energy, as generated and measured in diverse experiments.

It is necessary to measure the electrical power input to LENR experiments and the thermal power that leaves them as a function of time over a time period. The thermal power is the sum of the input power and LENR power. The ratio of total output power to input power at any time is called the “power gain”. Integration of those two powers over part or all of an experimental run for the same time period gives the input and output energies. The ratio of the partial or total energy output to the similar energy input is the “energy gain”. As already noted, the output thermal energy minus the input electrical energy is called “excess heat”.

Given these basic facts and conventions, the means for measuring the input electrical power and the output thermal power are critical to the determination of gain values and the excess heat due to LENR. The techniques used depend on having good equipment, proper calibrations and accurate data analysis. Additional details on input and output power measurements are provided in the rest of this section.

Electrical power measurements are very common in electrical engineering and its many applications. Voltage is basically energy per charge. Current is charge per second. Hence, the product of voltage  $V$  and current  $I$  gives energy per second, which is electrical power  $P$ . That is,  $P = V \times I$  at any instant. This means that measurement of electrical power as a function of time requires separate measurements of voltage applied to a LENR experiment and the current that

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<sup>17</sup> <https://www.iscmns.org/library.htm>.

<sup>18</sup> <http://www.infinite-energy.com/whoarewe/whoarewe.html>

<sup>19</sup> <http://news.newenergytimes.net/>.

<sup>20</sup> <http://world.std.com/~mica/cft.html>.

<sup>21</sup> <http://coldfusionnow.org/>.

enters the experiment. Commercial equipment for power measurements is widely available. As one example, this author has used the following equipment for quantification of electrical power input to one LENR experiment: the VOLTECH PM3000. It separately measured and logged the instantaneous voltage and current values 50,000 times per second. Many other examples could be given, and have been used in LENR experiments.

While electrical power measurements are familiar to many scientists and engineers, such is not the case for thermal power measurements. However, thermal measurements are not rare. They are done routinely in the food industry to produce the caloric values required on food packages<sup>22</sup>. But, those measurements are done by specialists in companies providing such services. The instruments used in the food and other industries, and in some scientific experiments, are called calorimeters. One of the early and enduring problems in the assimilation of results of LENR experiments is the fact that most physicists are not familiar with calorimetry. Hence, we now provide some information on calorimeters and their use.

Calorimeters produce output voltage signals that are directly related to the thermal power generated within such systems. The usually-graphical relationship between thermal power and output voltage is called a calibration curve. It is commonly produced by use of electrical resistors within a calorimeter. The power they dissipate can be measured accurately using the same ideas and methods as are employed to determine the electrical power input to a LENR experiment, that is, measurement of current through a resistive heater due to a known applied voltage. Varying the voltage, and with it the current into a resistor, gives variations in the power input to the calorimeter during its calibration. The output signal is measured for each input power level, and a plot of the values over a range of input powers is the calibration curve. During or after a LENR experiment, the combination of the measured output voltage from a calorimeter and the calibration curve is used to obtain the experimental output thermal power.

Just as there are many ways to measure electrical input power, there are numerous types of calorimeters and means to use them. Most of them work by using insulation around the cell in a LENR experiment to impede the heat produced by both the input electrical power and LENR from reaching the surroundings. Means to limit heat conduction, convection and radiation are employed. This leads to a temperature rise in the interior liquid. A hydrodynamic analogy is useful for considering how such calorimeters work. Imagine water (a surrogate for heat) being poured into a bucket (the analog of the calorimeter), which has holes in it (analogous to heat leaks from the calorimeter). The level of water in the bucket (equivalent to temperature) will depend on the rate of water inflow (equivalent to interior heat production) and the rate of water outflow (similar to heat leaking through the insulation). The key measurement in calorimetry is the temperature within the interior volume compared to the outside temperature. The temperature difference can be uniquely related to the output power level by proper calibration.

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<sup>22</sup> Note that a food calorie is equal to 1000 calories in physics, each of which is equal to 4.186 Joules.

There are many types of calorimeters, which operate on different principles. One that is often employed in LENR experiments uses a thermoelectric material to measure the temperature difference across the insulation around the cell. A commercial calorimeter of this type was bought by this author about twenty year ago for LENR experiments at the Naval Research Laboratory. Detailed papers on seven types of calorimeters are in the Proceedings of ICCF-14<sup>23</sup>, a conference chaired by this author in 2008. They are listed here to illustrate the variety of calorimeter types and to cite experts on each of the types:

- “Twenty Year Review of Iso-peribolic Calorimetric Measurements of the Fleischmann-Pons Effect” by M. H. Miles and M. Fleischmann
- “The Method and Results Using Seebeck Calorimetry” by E. Storms
- “Construction of a Seebeck Envelope Calorimeter and Reproducibility of Excess Heat” by W.-S. Zhang, J. Dash and Z.-L. Zhang
- “Mass Flow Calorimetry” by M. C. H. McKubre and F. Tanzella
- “A High Accuracy Calorimeter for Cold Fusion Studies” by S. R. Little, G. A. Luce, M. E. Little
- “Constant Heat Flow Calorimeter” by T. V. Lautzenhiser, D. W. Phelps and M. Eisner
- “A Simple Calorimetric Method to Avoid Artifacts in a Controversial Field: The Ice Calorimeter” by J. Dufour, X. Dufour, D. Murat and J. Foos

Other reviews of calorimeters, and related experimental and numerical techniques are available. For example, Storms’ second book has brief reviews of six types of calorimeters<sup>24</sup>. They include Iso-peribolic, Seebeck, Adiabatic, Flow, Phase Change and Infrared Radiation systems. Calorimeters with the ability to detect 20 mW of thermal power are commonly used in LENR experiments. Sensitivities of 2 mW have also been achieved in several experiments. A few calorimeters, which were able to resolve less than 1 mW, have been used in LENR experiments.

The bottom line for measurement of thermal power from LENR experiments is that many types of reliable calorimeters exist. They can be calibrated properly to produce sensitivities that are more than sufficient to measure excess power from successful LENR experiments. Having this background, the next section summarizes some of the many results from power and energy measurements in LENR experiments.

## 5. Energy Production Measurements

Since Fleischmann and Pons reported about four watts of excess power in 1989, and because there was a widely recognized need for new sources of energy, production of heat by LENR got great attention at the beginning of the field. Such interest has remained the case since then, and continues to this day. There have been many hundreds of LENR experiments in which heat was the primary measurement. This section discusses reports from the body of technical literature on LENR experiments, which include evidence of significant levels of thermal power and energy

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<sup>23</sup> D.J. Nagel and M. E. Melich (Editors), “Proc. of the 14th Int’l Conf. on Condensed Matter Radiation Sciences”, <http://www.iscmns.org/iccf14/ProcICCF14a.pdf> and <http://www.iscmns.org/iccf14/ProcICCF14b.pdf>.

<sup>24</sup> E. Storms, “The Explanation of Low Energy Nuclear Reaction”, pp. 106-109, Infinite Energy Press (2014).

generation. Here we highlight a few papers with strong evidence of production of “excess heat”, that is, output thermal energy well in excess of the input electrical energy. Data from the reports, therefore, show that the experiments were operable. These data also demonstrate that LENR technology has utility for energy generation. A new clean energy technology should be welcome in a world burdened by the environmental and other bad effects of the massive use of fossil fuels.

### (1) Fleischmann and Pons

Fleischmann and Pons contributed many papers to the literature on LENR over about two decades. A useful summary of their contributions to the science of LENR is in a recent book reviewing the career of Martin Fleischmann<sup>25</sup>. Here, we concentrate on two of the many papers from Fleischmann and Pons, their long 1989 report and a 1993 paper on cells that continued to produce power after boiling dry, as well as one of their early patent documents.

A key paper by Fleischmann and Pons was sent to a journal ten days before their infamous press conference<sup>1</sup>. This paper caused three major problems, which were subsequently addressed. Having the words “nuclear fusion” in the title drew fast and furious objections from physicists. Secondly, that wording caused many efforts to prove the existence of fusion reactions, rather than consideration of nuclear reactions more generally. And, the paper included gamma ray spectra that were problematic. Despite these difficulties, the paper contains very significant data on the results of many electrochemical experiments with palladium cathodes in heavy water electrolytes. Three cathode geometries were employed in the experiments, rods, sheets and a cube. Significant excess heats in both watts and watts/cm<sup>3</sup> of the cathode were reported.

Fleischmann and Pons started their experiments on loading deuterons into palladium long before the controversial press conference in March of 1989. They were already performing such experiments at least four years earlier. In or about February of 1985, they were running an electrochemical experiment in which the cathode was a cube of palladium one centimeter on a side. They came to laboratory one morning to find that the experiment was destroyed. They described the situation in the 1989 journal article<sup>1</sup> with the statement: “We have to report here that under the conditions of the last experiment, even using D<sub>2</sub>O alone, a substantial portion of the cathode fused (melting point 1554 °C), part of it vaporized, and the cell and contents and a part of the fume cupboard housing the experiment were destroyed.” This event was investigated by the author, and details are given in a recent paper<sup>26</sup>. The meltdown occurred, but apparently was never documented. Fleischmann and Pons were probably concerned about possible interference from university or government officials.

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<sup>25</sup> “Developments in Electrochemistry: Science Inspired by Martin Fleischmann”, D. Pletcher, Z.-Q. Tian and D. Williams (Editors), Wiley (2014).

<sup>26</sup> D. J. Nagel and A. E. Moser, “High Energy Density and Power Density Events in Lattice-enabled Nuclear Reaction Experiments and Generators”, *J. Condensed Matter Nuclear Science*, vol. 19, pp.219-229 (2016).

In 1990, this reviewer went to the U. S. Patent and Trademark Office, and copied a patent application by the Fleischmann-Pons research group<sup>27</sup>. One figure from the document has gotten widespread attention, since it was first used in presentations<sup>28</sup>. A version of the figure, with lines and slopes added by McKubre, is shown in Figure 2. These data have some remarkable features. First, the temperature was trending upward slowly (about 2.2°C per day), probably due to increasing resistance within the electrochemical cell. Then, the temperature rose quickly about twelve degrees soon after one addition of D<sub>2</sub>O. Such additions were done each 12 hours to compensate for the heavy water lost by electrolysis. After that, the temperature increased at a higher rate of about 6.5 degrees per day. Approximately two days later, the slope became even higher, and the temperature neared boiling. Another addition of D<sub>2</sub>O caused a drop of about 20°C. After the drop, both the temperature and its trend matched the extension of what was seen before the large temperature excursion for roughly two and a half days. That behavior is consistent with the idea that the electrolyte resistance was increasing at the same rate throughout the experiment. Reasons for the observed large increases and decrease are not known. But, temperature measurements like these are routine, and the data in Figure 2 undoubtedly show what actually happened in that experiment.

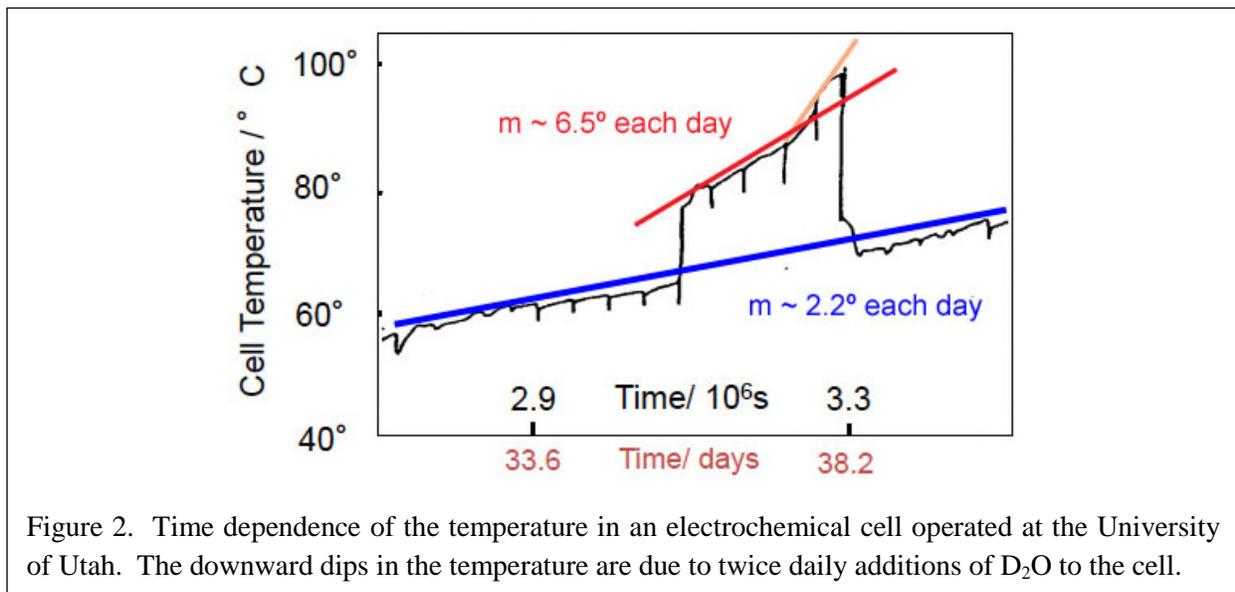


Figure 2. Time dependence of the temperature in an electrochemical cell operated at the University of Utah. The downward dips in the temperature are due to twice daily additions of D<sub>2</sub>O to the cell.

In 1993, Fleischmann and Pons published a paper on the electrolysis of heavy water with palladium cathodes<sup>29</sup>. They reported high rates of energy generation “(>1kW/cm<sup>3</sup>) at temperatures close to (or at) the boiling point of the electrolyte”. They showed an image of four cells side by side, each of which boiled dry. Even more remarkable is the fact that the cells

<sup>27</sup> S. Pons, M. Fleischmann, C. Walling and J. Simpson, International Patent Application No 90/10935 (1990).

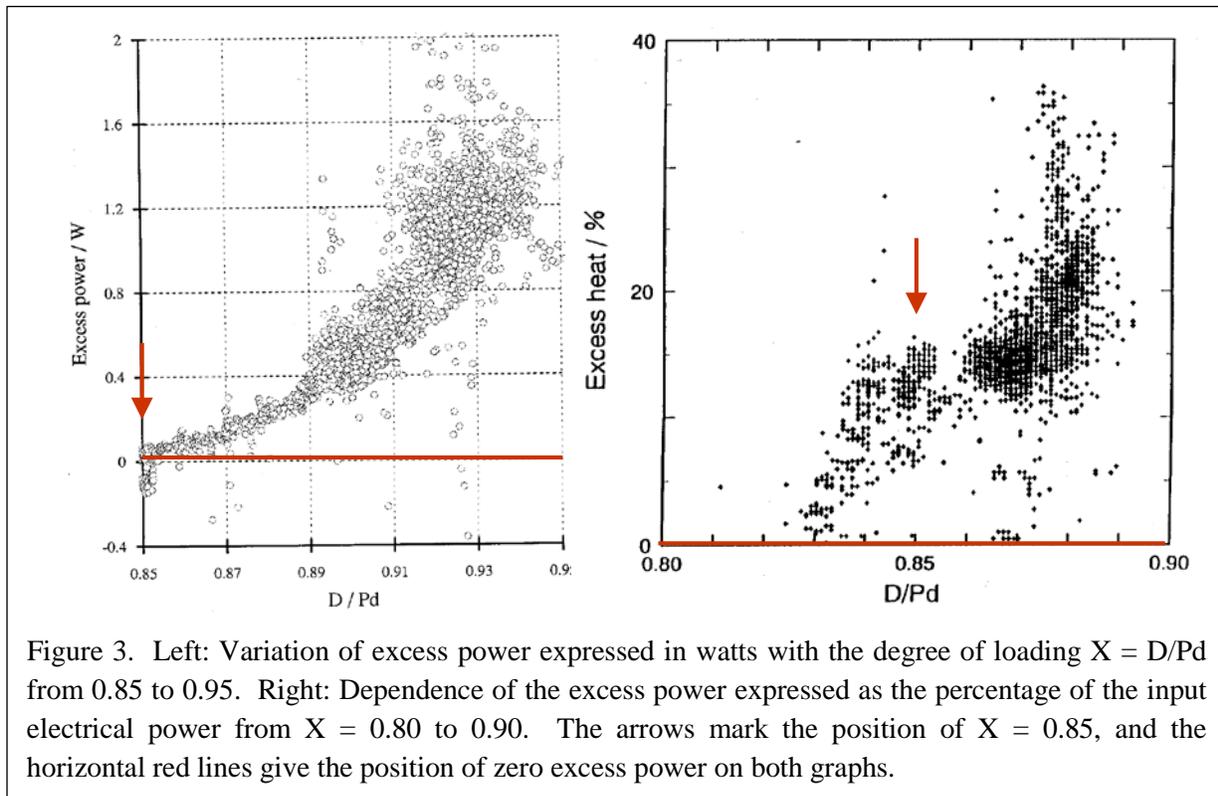
<sup>28</sup> D.J. Nagel, “Cold Fusion, Problems, Progress and Prospects”, The George Washington University (2003).

<sup>29</sup> M. Fleischmann and Pons, “Calorimetry of the Pd-D<sub>2</sub>O System: from Simplicity via Complications to Simplicity”, Physics Letters A, vol. 176, pp. 118-129 (1993) and S. Pons and M. Fleischmann, “Heat After Death”, Proc of the Fourth International Conference on Cold Fusion, Transactions of Fusion Technology, vol. 26, No. 4T, pp. 87-95 (1994).

continued to produce energy after the current was disrupted by the absence of the electrolyte between the electrodes. That behavior has been termed “Heat After Death” (HAD). The “death” refers to cessation of the operation of the electrochemical cell, which could no longer maintain a current. It has been seen by other scientists, when they turned off cells that were producing excess heat. An example is in Figure 7 below. Operability of LENR was demonstrated by the excess heat produced in these experiments. Utility of these operable devices was demonstrated when their design and methods were subsequently used in other operable LENR experiments.

## (2) Parametric Variations

Early in the history of the laboratory study of LENR, scientists naturally varied experimental parameters to determine their importance. Studies in the U.S. and Japan focused on the same two parameters. The first was the “degree of loading”, which is defined as the ratio of the number of deuterons (D) to the number of palladium atoms (Pd) in a cathode, conventionally,  $X = D/Pd$ . This quantity is generally obtained by making resistance measurements on the cathode material during an experiment, because that parameter is related to the degree of loading. The other variable was current density, or the number of millamps of electrical current flowing into the cathode divided by its area, that is, mA/cm<sup>2</sup>. The current is measured by an ammeter and the area is computed from the measured cathode geometry. Importantly, the measurements in the U.S. and Japan showed similar variations. They will now be summarized.



Variations of the excess power as a function of the degree of loading are shown in Figure 3<sup>30,31</sup>. Both data sets show that excess power increases approximately as the square of the degree of loading above a threshold in the range of  $X = 0.80$  to  $0.85$ . While the agreement is imperfect, the data do support each other, both evidently and because of their being obtained in distinct experiments in two very different settings, one in the U. S. and the other in Japan. Many other results on the dependence of LENR heat production on the degree of loading can be given<sup>32</sup>. McKubre and Tanzella published data that show the much-trumpeted early failures to measure excess heat at both MIT and CalTech were due to their inability to get to the necessary high degrees of loading<sup>33</sup>.

The dependence of excess power on current density was measured by Fleischmann and Pons<sup>34</sup>, and by the groups at SRI International<sup>30</sup> and in Japan<sup>31</sup>. Two of those results are given in Figure 4. In both cases, the excess power varied approximately linearly with current density above a

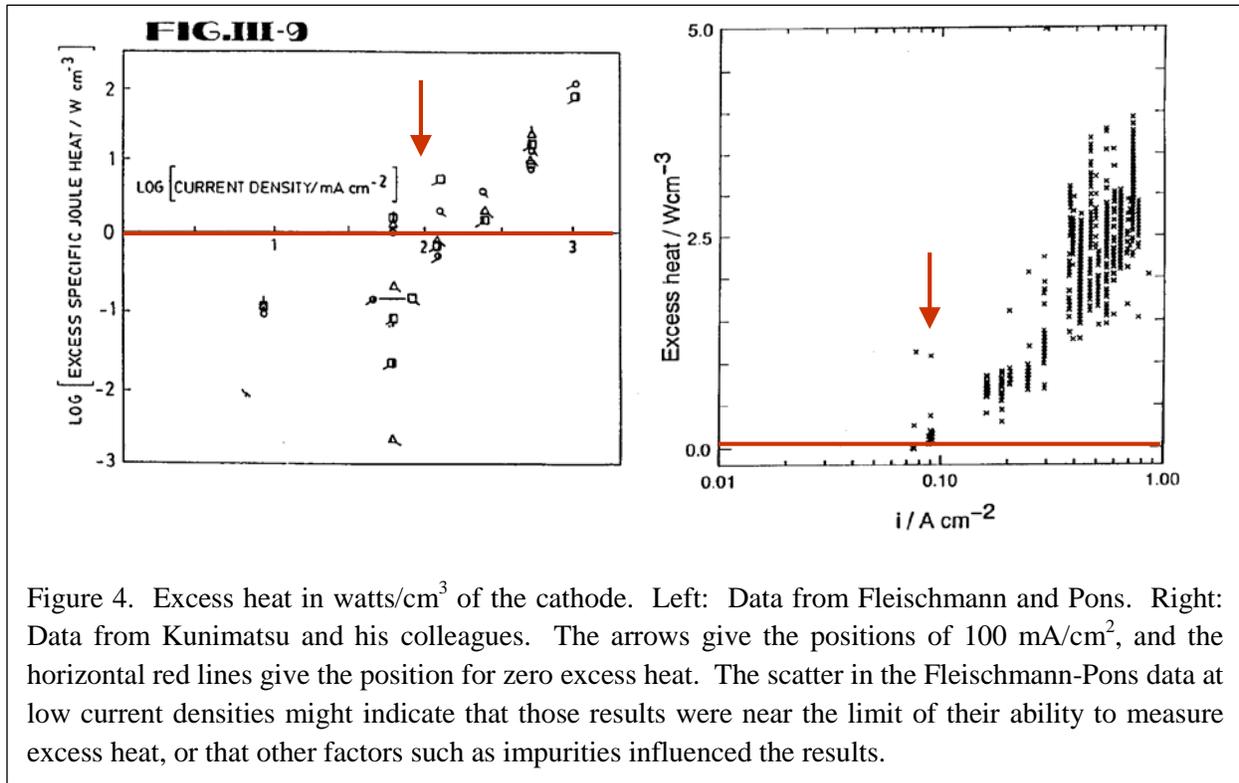


Figure 4. Excess heat in watts/cm<sup>3</sup> of the cathode. Left: Data from Fleischmann and Pons. Right: Data from Kunimatsu and his colleagues. The arrows give the positions of 100 mA/cm<sup>2</sup>, and the horizontal red lines give the position for zero excess heat. The scatter in the Fleischmann-Pons data at low current densities might indicate that those results were near the limit of their ability to measure excess heat, or that other factors such as impurities influenced the results.

<sup>30</sup> M. C. H. McKubre *et al.*, "Excess Power Observations in Electrochemical Studies of the D/Pd System; the Influence of Loading", in Third International Conference on Cold Fusion, "Frontiers of Cold Fusion". pp. 5-18, Universal Academy Press, Inc., Tokyo, Japan (1992).

<sup>31</sup> K. Kunimatsu *et al.*, "Deuterium Loading Ratio and Excess Heat Generation during Electrolysis of Heavy Water in a Palladium Cathode in a Closed Cell Using a Partially Immersed Fuel Cell Cathode" in Third International Conf. on Cold Fusion, "Frontiers of Cold Fusion". pp. 31-45, Universal Academy Press, Inc., Tokyo, Japan (1992).

<sup>32</sup> E. Storms, "How Basic Behavior of LENR can Guide a Search for an Explanation", J. Condensed Matter Nuclear Science, vol. 20, pp. 100-138 (2016).

<sup>33</sup> M. C. H. McKubre and F. Tanzella, "What is Needed in LENR/FPE Studies", J. Condensed Matter Nuclear Science, vol. 8, pp. 187-197 (2012).

<sup>34</sup> M. Fleischmann and S. Pons, "Calorimetry of the Palladium-D-D<sub>2</sub>O System" in Proceedings of the EPRI-NSF Workshop on Anomalous Effects in Deuterided Metals, 16-18 October 1989, pp. 3-1 to 3-50 (1993).

threshold near 100 mA/cm<sup>2</sup>. The experiments at SRI International showed similar behavior, but with a threshold near 250 mA/cm<sup>2</sup>.

Two authors have compiled data on excess heat as a function of current density<sup>35,36</sup>. One of their plots is shown in Figure 5<sup>36</sup>. The different experiments gave somewhat different thresholds for the current density needed to produce LENR, and the dependence on current density (the slopes) also varied. But, the overall linear variation of excess power with current density is clear in most of the cases. One experiment with flow varied significantly from linear behavior.

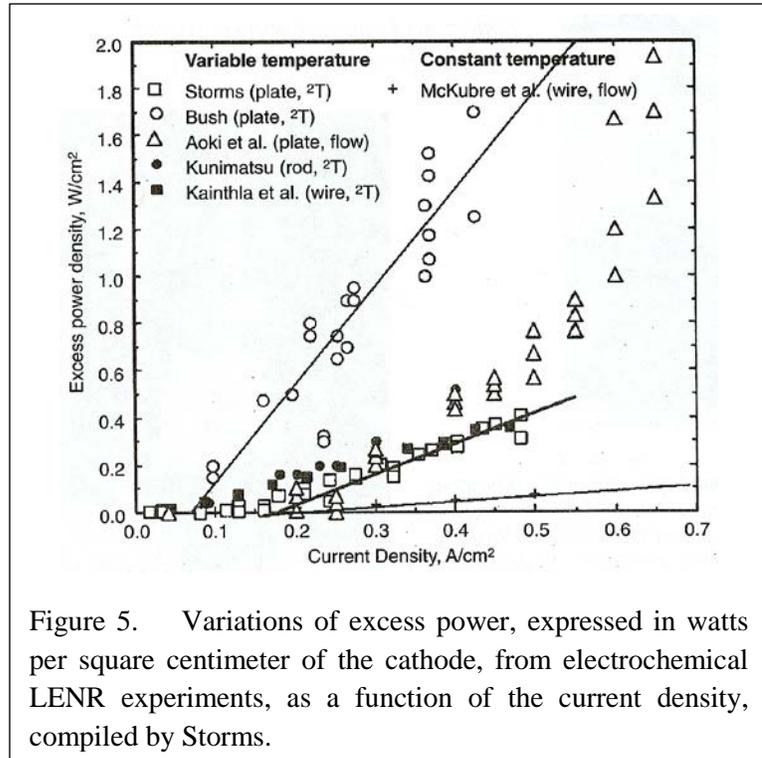


Figure 5. Variations of excess power, expressed in watts per square centimeter of the cathode, from electrochemical LENR experiments, as a function of the current density, compiled by Storms.

### (3) Preparata

In 1996, Preparata, who was a theoretician from Italy, reported the results of an unusual LENR experiment. The cathode was a wire of Pd 50 μm in diameter. It was configured to have a current flowing along its length of 250 cm, as well as between it and the anode<sup>37</sup>. The motivation for the current within the cathode was the fact that an electron current can influence the distribution of nuclei within a conductor. The process is called electromigration. It is due to transfer of momentum from the moving electrons to ions with which the electron collide inside of a conductor. One of the experiments described by Preparata was run for 16,000 seconds, with the maximum input power of about 500 W and maximum excess power of over 300 W. Normalizing the excess power to the volume of the cathode gave remarkable values in the range of 50 to 100 kW/cm<sup>3</sup>. These values exceed those of nuclear fuel rods in fission reactors. A blank experiment with a Pt wire in place of the Pd wire gave an approximate balance between input electrical energy and the output thermal energy. This is one of the many LENR experiments that should be repeated with additional instrumentation.

<sup>35</sup> T. Aoki *et al.*, “Helium and Tritium Concentrations in Electrolytic Cells”, Transactions of Fusion Technology, vol. 26, no. 4T, pp. 214-220 (1994).

<sup>36</sup> E. Storms, “The Science of Low Energy Nuclear Reaction”, p.77, World Scientific (2007).

<sup>37</sup> G. Preparata, “Everything You Always Wanted to know About Cold Fusion Calorimetry?” in “Progress in New Hydrogen Energy”, Proc. of the Sixth International Conference on Cold Fusion, pp. 136-143.(1996).

(4) Arata and Zhang

These authors published many reports of LENR heat generation. An interesting characteristic of their reports of excess heat is the length of their experimental runs, sometimes as long as 8500 hours (nearly one year). Examples of their energy generation results from 1994 and 1995 are shown in Figure 6<sup>38</sup>. It is seen that the ability to produce LENR energy was sustained for times of about 100 days, that is, well over one quarter of one year. The values of excess power of 60 kJ/hr correspond to over 15 watts. These data bode very well for the commercial utility of LENR energy generators, even though it was not possible to control the rate of energy generation in those experiments.

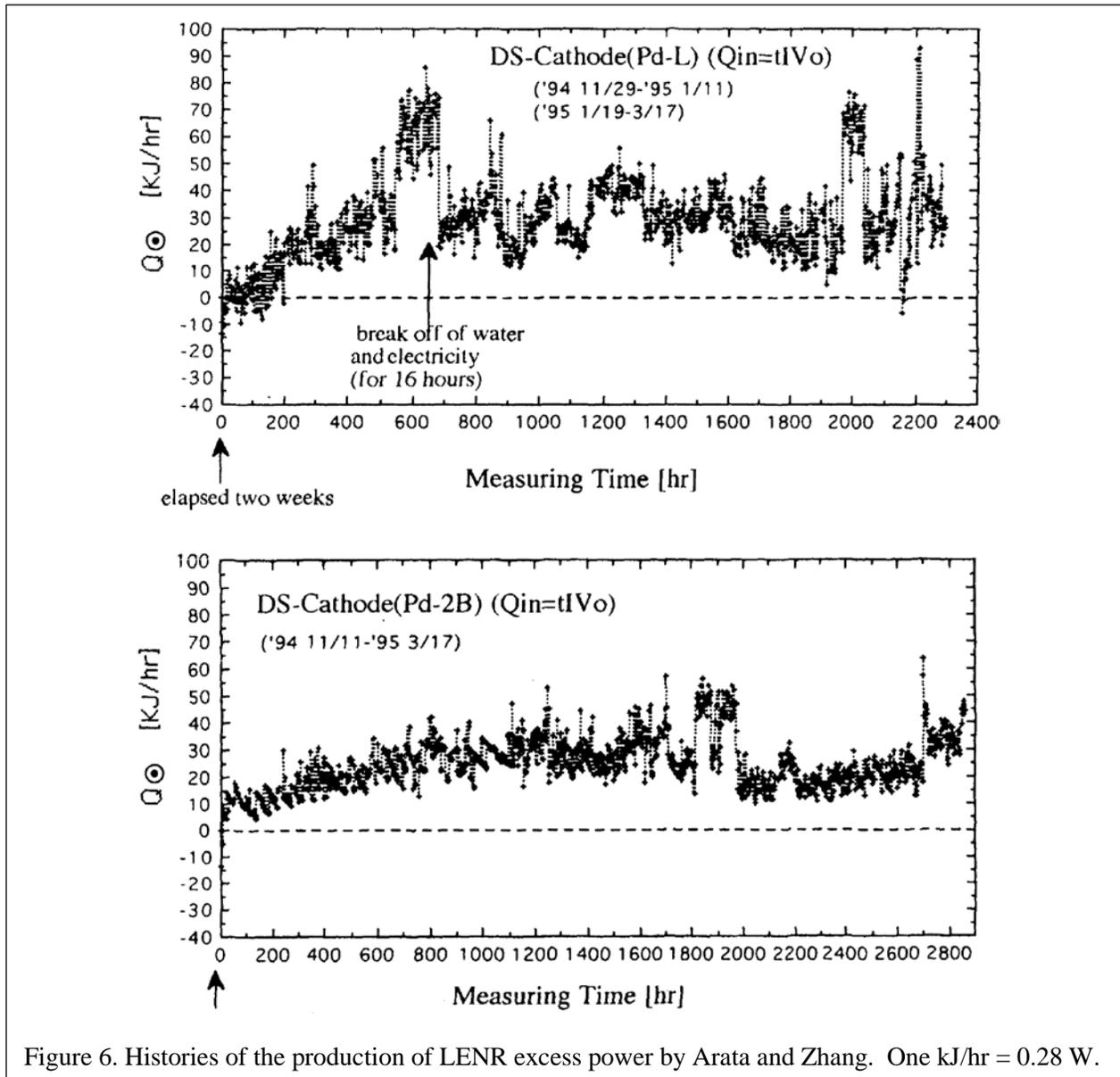


Figure 6. Histories of the production of LENR excess power by Arata and Zhang. One kJ/hr = 0.28 W.

<sup>38</sup> Y. Arata and Y.-C. Zhang, "Cold Fusion Reactions Driven by 'Lattice Quake'", Proc. Japan Academy, 71, Ser. B p. 98 (1995).

(5) Swartz and Verner

Different approaches to the production of excess heat have been taken by Swartz and his colleagues in their company, Jet Energy, Inc.<sup>39</sup> They used high impedance electrochemical cells called PHUSORs and small, two terminal devices termed NANORs. Both names are registered trademarks. Very sophisticated measurements have been taken with these types of devices, both of which exhibit LENR energy production. Figure 7 is one example of high quality data from a PHUSOR<sup>40</sup>. It shows a balance between the input electrical and output thermal power for the control, which proves that the power measurement systems worked as they should. The data in that figure also show clear excess energy from the PHUSOR. When the power input to the PHUSOR was turned off, it continued to produce energy for a few hours, the effect called “Heat After Death” (HAD) by Fleischmann and Pons. The very good signal-to-noise values for the data shown in Figure 7 are noteworthy.

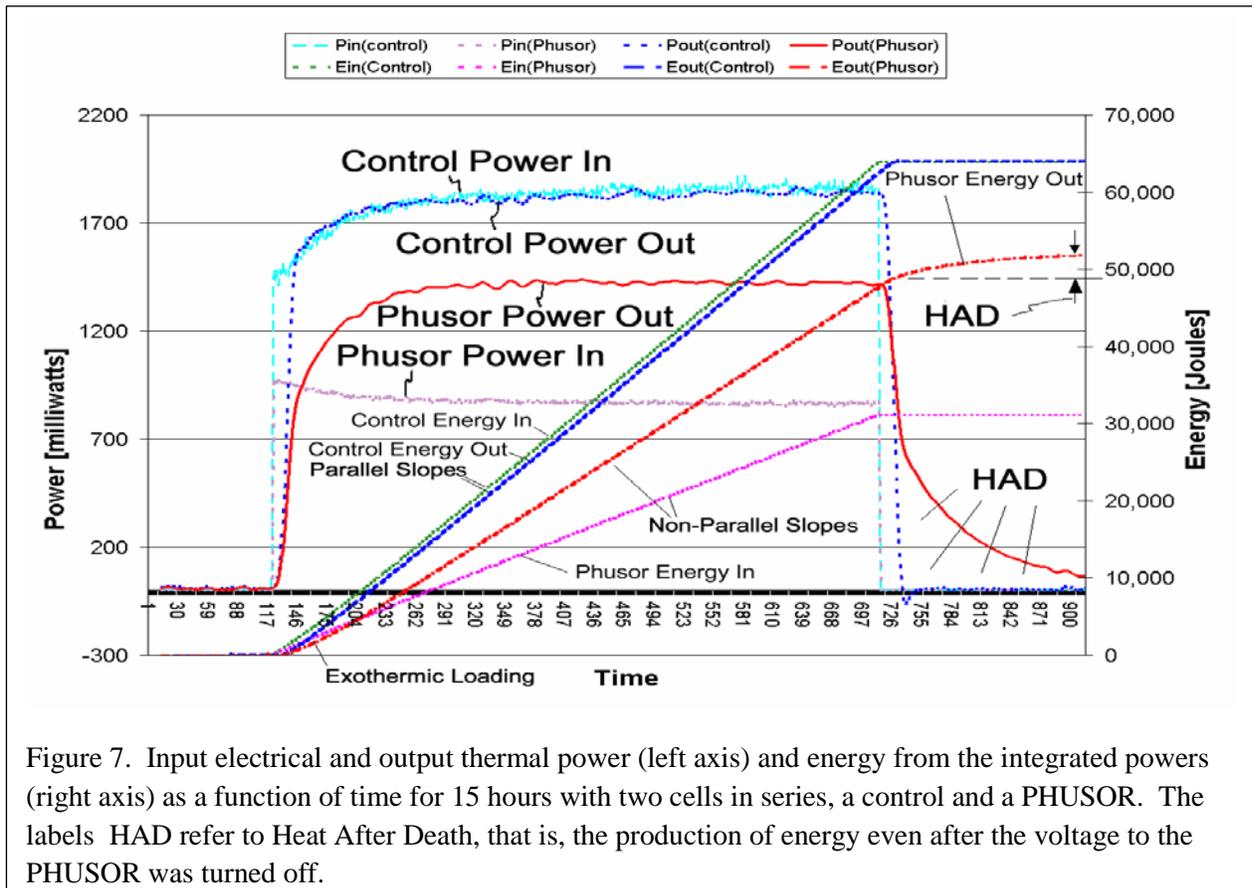


Figure 7. Input electrical and output thermal power (left axis) and energy from the integrated powers (right axis) as a function of time for 15 hours with two cells in series, a control and a PHUSOR. The labels HAD refer to Heat After Death, that is, the production of energy even after the voltage to the PHUSOR was turned off.

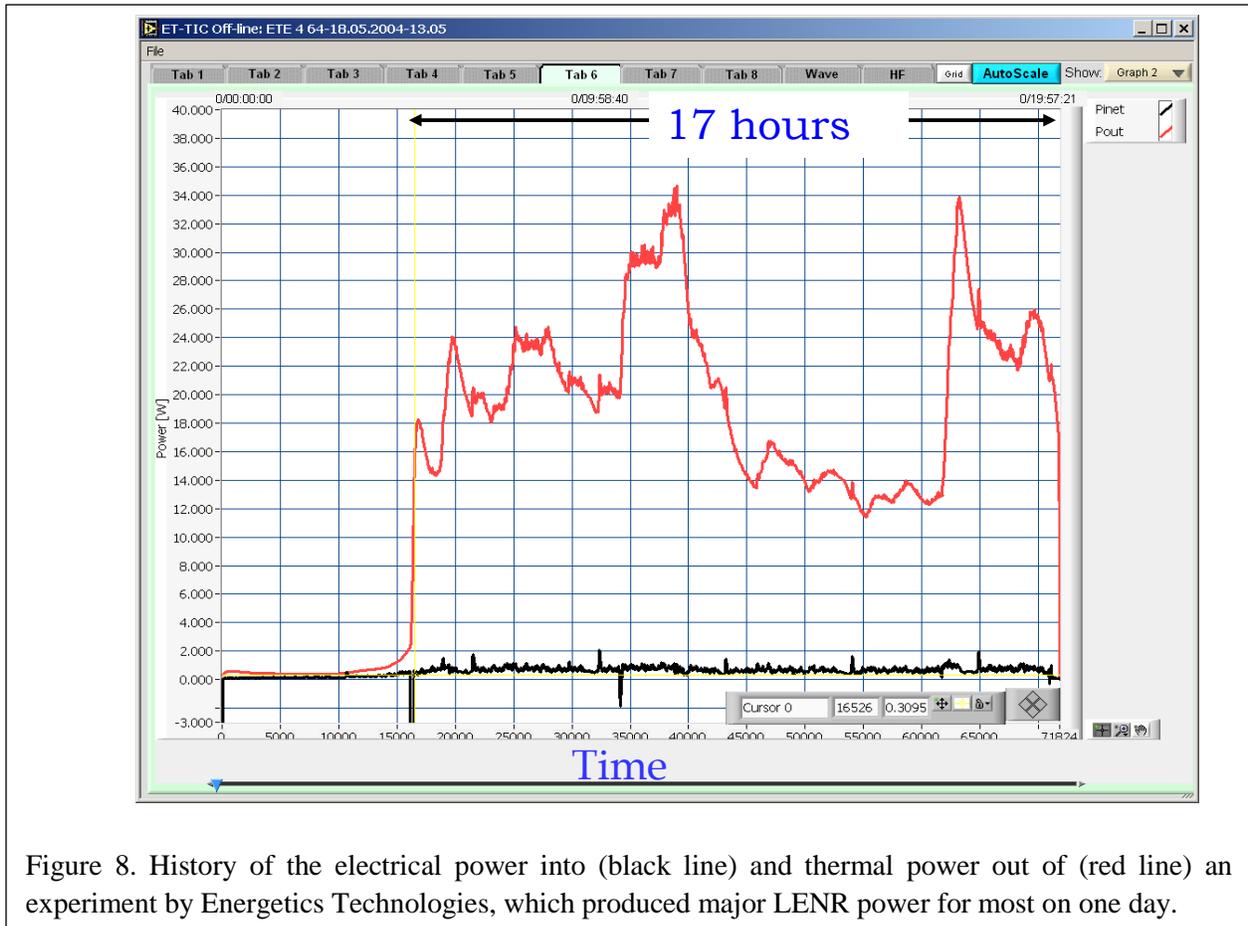
<sup>39</sup> <http://world.std.com/~mica/jettech.html> and <http://world.std.com/~mica/jettechnology.htm>.

<sup>40</sup> M. Swartz and G. Verner, “Dual Ohmic Controls Improve Understanding of ‘Heat after Death’”, Transactions American Nuclear Society, vol. 93, pp. 891-892 (2005).

## (6) Energetics Technologies

A company in Israel produced some very important LENR energy generation data, and reported it in 2004. They had many good results with palladium cathodes. The best one is shown in Figure 8<sup>41</sup>. The average LENR power was about 21 W, and the energy gain for the duration of the experiment was 26. In this case, as in others, there was no control over power production. It is highly likely, once the mechanisms behind LENR are understood, there will be the power control needed for commercial generators.

The work shown in Figure 8 was so important that a team was formed between SRI International and the Italian laboratory ENEA to reproduce the results<sup>42</sup>. They attained energy gains as high as five. It is noted in passing that the work of the Israeli company was featured on U.S. prime-time television by CBS in 2009. That video is still available to CBS subscribers<sup>43</sup>.



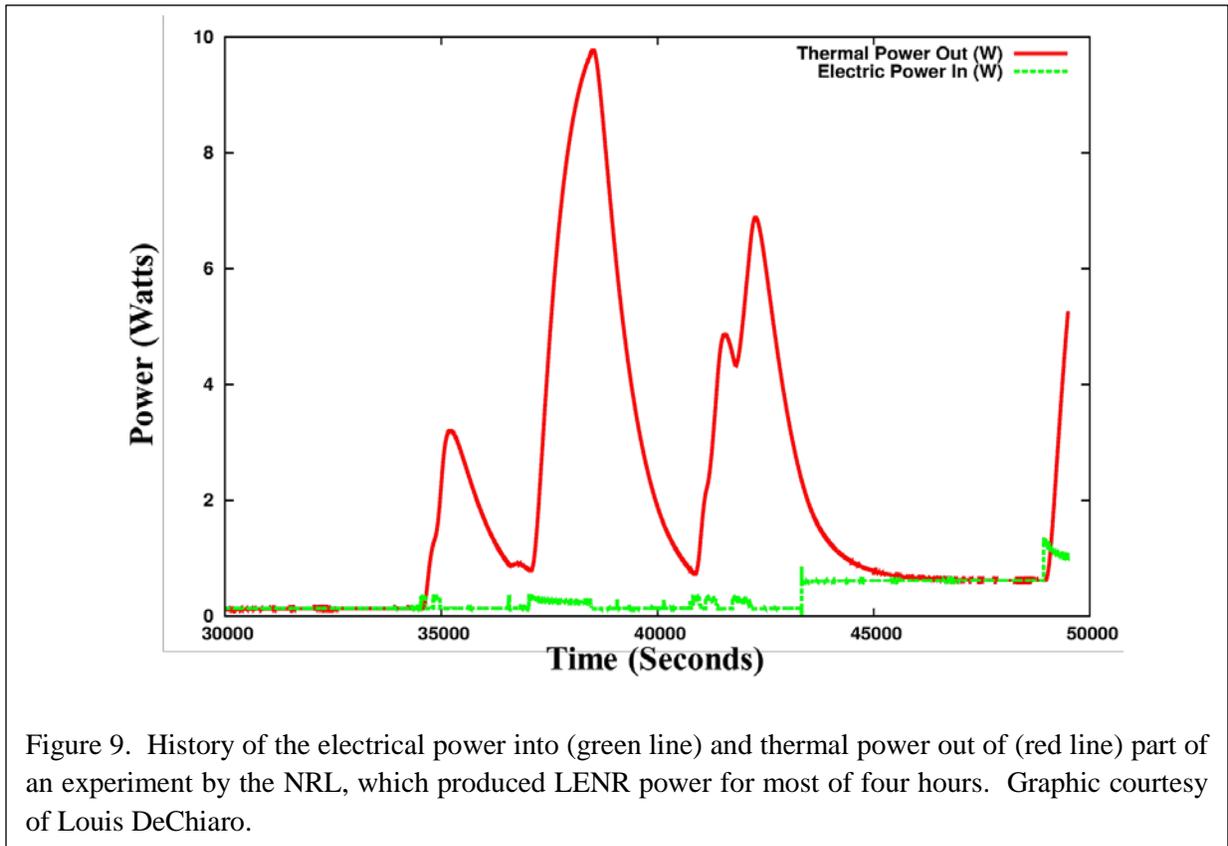
<sup>41</sup> I. Dardik *et al.*, “Excess Heat in Electrolysis Experiments at Energetics Technologies”, Proceedings of the 11<sup>th</sup> International Conference on Condensed Matter Nuclear Science, J.-P. Biberian (Editor), World Scientific, pp. 84-101 (2006).

<sup>42</sup> M. C. H. McKubre *et al.*, “Replication of Condensed Matter Heat Production” in “Low Energy Nuclear Reactions Sourcebook”, J. Marwan and S. B. Krivit (Editors), American Chemical Society, pp. 219-247 (2008).

<sup>43</sup> <http://www.cbsnews.com/news/cold-fusion-is-hot-again/>.

## (7) Naval Research Laboratory

The Corporate Laboratory of the U.S. Navy performed many LENR experiments for about 25 years. Their success rate in producing excess heat was low, only a few percent. However, they obtained strong results in a few experiments. The situation was somewhat similar to the experience of Energetics Technologies and other laboratories performing LENR experiments. Results from part of one of the best runs at the Naval Research Laboratory (NRL) are given in Figure 9<sup>44</sup>. The cathode was an alloy of 90% Pd and 10% Rh. The highest power gain for that experiment was approximately 40. The energy gain for the entire experiment was over six. As with the data shown in Figure 8, the NRL output power was both sporadic and uncontrolled.



## (8) Other Reports on Heat Production

Excess heat production in LENR experiments was also reported by Gozzi's team in Italy in the 1990s. The time variation was erratic and uncontrollable. However, excess power values as

<sup>44</sup> D. Dominguez *et al.*, "Evidence for Excess Energy in Fleischmann-Pons-Type Electrochemical Experiments", *J. Condensed Matter Nuclear Science*, vol. 14, pp. 15–28 (2014)

high as 10 W were measured. They are shown in Figure 14 below. In another paper by the same group, excess powers above 10 W were reported, as well as generation of tritium and helium<sup>45</sup>.

Overall, there are hundreds of reports on the results of many hundreds of LENR calorimetry experiments. A compilation of excess heat results is in the first of Kozima's books<sup>46</sup>. Storms' first book has a table over eight pages long that lists reports of anomalous heat production in dozens of LENR experiments up until 2007<sup>47</sup>. Many of the reported excess energies are a few watts or less. Such power, however, can be measured with confidence using various well-calibrated calorimeters. Further and critically important is the fact that many measurements showed heat production far beyond what can be explained by chemistry. As one example, McKubre and his team reported thermal generation data of 2076 eV per Pd atom, many times greater than any conceivable chemical processes<sup>48</sup>.

#### (8) Conclusion Regarding LENR Heat Generation

Numerous experiments by competent scientists in many laboratories in several countries have shown that it is possible to generate energy from LENR. Measured "excess energy" has often been far beyond both the sensitivity of the instruments and what can be explained by chemistry. Large energy gains (thermal energy out divided by electrical energy in) have been reported. Reproducibility and controllability of LENR experiments are still imperfect due to some unknown factor(s). But that does not obviate either the reality of LENR or the considerable potential of LENR to provide a new clean source of distributed energy. The heat generation data strongly demonstrates both the operability and utility of LENR.

## 6. Tritium Production Measurements

As noted in Section 1, the occurrence of chemical or nuclear reactions commonly causes two types of effects, energy and products. Either of them indicates that a reaction has occurred, and provides information on the characteristics of the reaction. Each of them has often been measured in many different LENR experiments, so that we know a great deal about such reactions. The last section reviewed energy from LENR. In this and the following two sections, data are presented on three LENR products, namely tritium, helium and other elements. None of the measured elements can be produced by chemistry. Hence, the following data show that LENR do occur, that is, LENR are operable. The possibility that tritium generation might also have utility is briefly noted at the end of this section.

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<sup>45</sup> D. Gozzi *et al.*, "Calorimetric and Nuclear Byproduct Measurements in Electrochemical Confinement of Deuterium in Palladium", *J. Electroanalytical Chemistry*, vol. 380, pp 91-107 (1995).

<sup>46</sup> H. Kozima, "Discovery of the Cold Fusion Phenomenon", pp. 46-54, Ohtake Shuppan (1998).

<sup>47</sup> E. Storms, "The Science of Low Energy Nuclear Reactions", pp. 53-61, World Scientific (2007).

<sup>48</sup> M. C. H. McKubre, Presentation at Short Course prior to the 10<sup>th</sup> International Conference on Cold Fusion, Cambridge MA (24 August 2003).

Tritium is the third isotope of hydrogen, after protium and deuterium. It is a very significant product from many LENR experiments. This isotope is radioactive with a relatively short half-life of  $12.32 \pm 0.02$  years<sup>49</sup>. Hence, it is not found in nature, except high in the atmosphere due to the incidence of cosmic rays. Further, decay of tritons produces charged particles, which makes them much easier to detect than neutrons:  ${}^3\text{T} > {}^3\text{He} + e^- + \nu$ . This decay releases 18.6 keV of energy. The electron kinetic energy varies, with an average of 5.7 keV. The remaining energy is carried off by the nearly undetectable electron antineutrino  $\nu$ .

There are a few methods for measurement of tritium. Detection of light due to scintillation in special organic liquids, which is caused by the energetic electrons from tritium decay, is one of the two most commonly used methods<sup>50</sup>. Photomultipliers are frequently used for the light detection because of their sensitivity. Table top systems for tritium quantification by scintillation measurements are commercially available<sup>51</sup>. Tritium is also frequently detected in the gas phase by measuring the ionization (charges) produced by the electron emitted during its decay. Various means of performing such measurements include the use of ion chambers, proportional counters or electrometers. Images of commercial gas phase instruments for tritium detection are available<sup>52</sup>. Mass spectrometry can also be used for tritium detection in the gas phase. However, that technique requires relatively large and expensive instruments with high mass resolution, and highly skilled operators. Hence, it is little used for tritium detection. Radiation from tritium decay can also be registered on photographic film, but this method is seldom used nowadays, since it is relatively cumbersome and more difficult to quantify.

Because it was initially thought that the heat reported by Fleischmann and Pons was due to fusion, and because conventional D-D fusion produces tritons, many laboratories looked for tritium in the liquids within electrolytic LENR experiments. A few prominent laboratories did find tritium in about the same time frame. The results from five of those groups will now be summarized. They include two universities, one institute, one U. S. national laboratory and a major government laboratory in India. Additional reports of tritium measurements are also cited.

#### (1) Texas A and M University

John Bockris of the Department of Chemistry at this university was one of the most respected electrochemists in the world. He was on the same high level as Martin Fleischmann in terms of his long career and large impact on the field. So, he began to try to replicate the Fleischmann-Pons results soon after the 23 March 1989 announcement. The subsequent work by Bockris and his students resulted in numerous papers, some of which were on the generation of tritium.

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<sup>49</sup> <https://en.wikipedia.org/wiki/Tritium>.

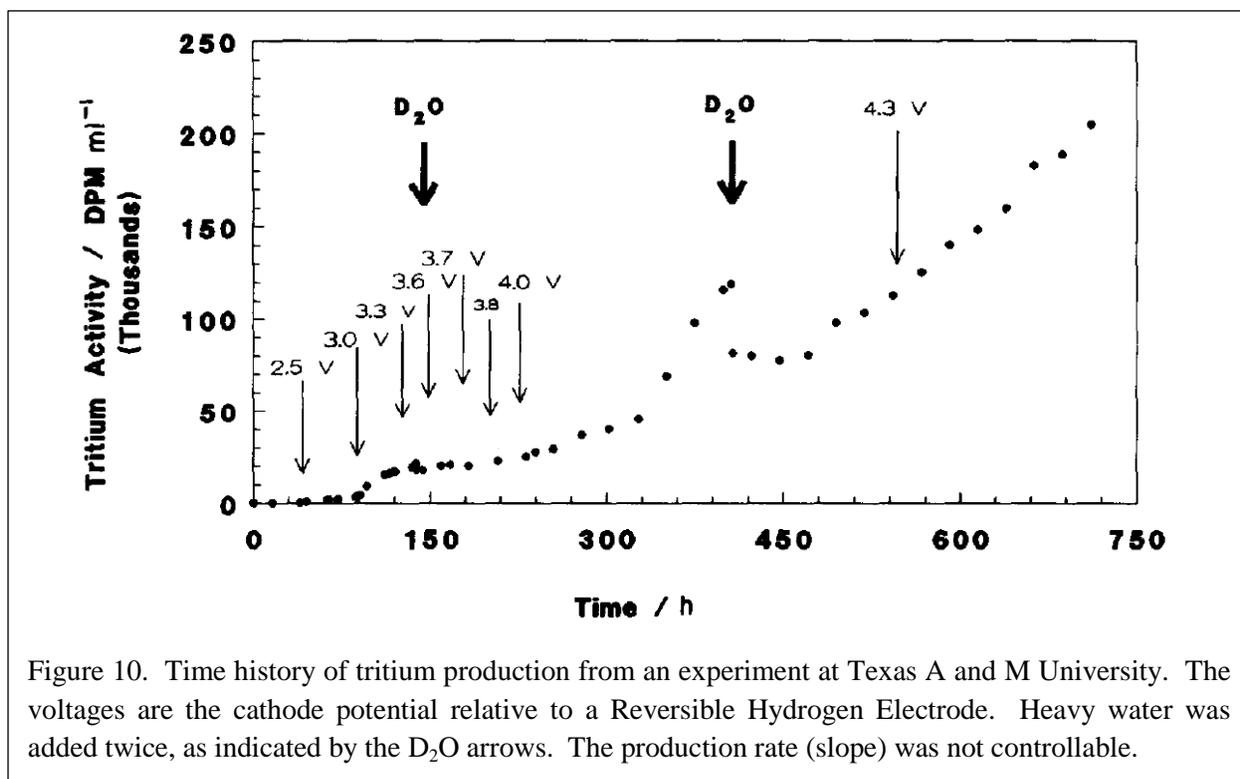
<sup>50</sup> [https://en.wikipedia.org/wiki/Liquid\\_scintillation\\_counting](https://en.wikipedia.org/wiki/Liquid_scintillation_counting).

<sup>51</sup> <http://www.sciencedirect.com/science/article/pii/0003269778907984>.

<sup>52</sup> [http://www.drct.com/Tritium\\_Detectors.htm](http://www.drct.com/Tritium_Detectors.htm).

The initial report of tritium production by the Bockris team was published in 1989 in a refereed journal<sup>53</sup>. The abstract reads “Here, we describe the observation of tritium produced in eleven D<sub>2</sub>O electrolysis cells at levels 10<sup>2</sup>-10<sup>5</sup> times above that expected from normal isotopic enrichment of electrolysis. Particular attention has been paid to possible sources of contamination.” Three different scintillation instruments were employed. Results from nine cells that did produce tritium were given, and data from 142 blank runs were provided.

Bockris and his colleagues published at least three more papers on tritium production by 1993. The key graphic from their 1992 paper is reproduced in Figure 10<sup>54</sup>. It shows the increase in tritium activity as a function of time during a month-long run of one cell. It is seen that the production of tritium was sensitive to the applied voltage. It decreased after the second addition of heavy water, which was done to compensate for the loss of electrolyte from the cell due to electrolysis of the heavy water. A few days later, the tritium production regained its earlier value. The reasons for this variability are not known, but the data are robust empirical observations and very significant. The good signal-to-noise ratio for these data is noteworthy.



<sup>53</sup> N. J. C. Packham *et al.*, “Production of Tritium from D<sub>2</sub>O Electrolysis at a Palladium Cathode”, *J. Electroanalytical Chemistry*, vol. 270, pp 451-458 (1989).

<sup>54</sup> C.-C. Chien *et al.*, “On an Electrode Producing Massive Quantities of Tritium and Helium”, *J. Electroanalytical Chemistry*, vol. 338, pp 189-212 (1992).

In a 1996 paper, Bockris stated that “The production of tritium from deuterium in Pd has more than 100 published confirmations”<sup>55</sup>. Even without so many replications, the tritium data from the Bockris group are solid, with strong values that were obtained with careful procedures.

### (2) Case Western Reserve University

This university was the other academic institution that reported strong early evidence for the production of tritium in electrochemical LENR experiments. Scientists there conducted experiments with a Fleischmann-Pons type of cell, and sought to measure tritium and neutrons. The neutron measurements were “inconclusive”. In contrast, many of the experiments gave strong evidence for the production of tritium. The Case Western group published a paper in two places, the proceedings of the first International Conference on Cold Fusion in 1990 and in a report to the government the same year<sup>56</sup>. The abstract of the paper indicated that “Enhancement of tritium in the D<sub>2</sub>O solution was found in two open-type glass cells as well as in four other cells with Ni anodes. The largest enhancement factor found was 50.”

### (3) The National Cold Fusion Institute

Background on this Institute in Salt Lake City UT is available on the web<sup>57</sup>. The NCFI conducted many experiments under the guidance of Fleischmann and Pons. Their work showed evidence of the production of excess heat, and many of their experiments resulted in production of tritium in easily-measured amounts. The results were reported in four papers in the period 1991-1994. Two papers were published in proceedings of ICCF-2<sup>58</sup> and ICCF-4<sup>59</sup>, and are available from the library at lenr.org. Two appeared in refereed journals<sup>60,61</sup>.

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<sup>55</sup> J. O'M. Bockris *et al.*, “Do Nuclear Reactions Take Place Under Chemical Stimulation”, *J. Scientific Exploration*, vol. 10, pp. 245-248 (1996).

<sup>56</sup> R.R. Adzic *et al.*, “Investigation of Phenomena Related to D<sub>2</sub>O Electrolysis at a Palladium Cathode”, Case Western Reserve University Report No. 80 930 October 1990. Available at [www.dtic.mil/dtic/tr/fulltext/u2/a236409.pdf](http://www.dtic.mil/dtic/tr/fulltext/u2/a236409.pdf).

<sup>57</sup> <http://socialarchive.iath.virginia.edu/ark:/99166/w6wh9xrh>

<sup>58</sup> F. G. Will, *et al.*, “Studies of Electrolytic and Gas Phase Loading of Palladium with Deuterium”, in Second Annual Conference on Cold Fusion, “The Science of Cold Fusion”, T. Bressani, E. Del Giudice and G. Preparata (Editors), Como, Italy, Societa Italiana di Fisica, Bologna, Italy, pp. 373-383 (1991).

<sup>59</sup> F. G. Will, K. Cedzynska, and D.C. Linton, “Tritium Generation in Palladium Cathodes With High Deuterium Loading”, in Fourth International Conference on Cold Fusion, Lahaina, Maui, Electric Power Research Institute 3412 Hillview Ave., Palo Alto, CA 94304 (1993) and *Trans. of Fusion Technology*, vol. 26, pp. 209-213 (1994).

<sup>60</sup> K. Cedzynska, and F. G. Will, “Closed-System Analysis of Tritium in Palladium”, *Fusion Technology*, vol.22, pp. 156-159 (1992).

<sup>61</sup> F. G. Will, K. Cedzynska, and D. C. Linton, “Reproducible Tritium Generation in Electrochemical Cells Employing Palladium Cathodes with High Deuterium Loading”, *J. Electroanalytical Chemistry*, vol. 360, pp. 161-176 (1993).

Since there was basically one experimental program at the NCFI, which lead to reports of tritium production, only one of the key papers will be noted here. The second refereed publication<sup>61</sup> had the following abstract:

Reproducible tritium (T) generation well above background has been observed in tightly closed D<sub>2</sub>SO<sub>4</sub>-containing cells in four out of four Pd wire cathodes of one type. Tritium analysis was performed before and after each experiment on the Pd, the electrolyte and the gas in the head space. No tritium generation was observed in four identical Pd cathodes in H<sub>2</sub>SO<sub>4</sub> cells operated at the same time under the same conditions. A cyclic loading-unloading regime with low current densities, rather than the usual continuous constant current regime, was employed to attain D/Pd and H/Pd loadings of 1±0.05 reproducibly. (D = Deuterium and H = Hydrogen) D/Pd loadings greater than 0.8±0.05 appear to be necessary to generate tritium. The largest amount of tritium, generated in 7 days of continuous electrolysis, was  $2.1 \times 10^{11}$  tritium atoms, compared with a background of  $4 \times 10^9$  tritium atoms. The concentration of tritium and its axial distribution in the Pd were determined and concentrations of up to  $9 \times 10^{10}$  atoms/g Pd were found compared with a maximum background of  $5 \times 10^8$  atoms/g. The T/D ratio in the Pd is about 100 times larger than in the electrolyte or gas and indicates that tritium generation occurs in the Pd interior rather than at its surface. No tritium generation was observed in two other types of Pd electrodes in D<sub>2</sub>SO<sub>4</sub>, despite the attainment of D/Pd ratios near 1:1. Thus high D/Pd ratios appear to be a necessary but not sufficient condition for tritium generation in D<sub>2</sub>SO<sub>4</sub> electrolysis.

The careful work by capable scientists in a well-funded laboratory is noteworthy, as are the reported results.

#### (4) Los Alamos National Laboratory

Claytor and his colleagues at the Los Alamos National Laboratory measured tritium produced in different types of LENR experiments. They reported the results of their experiments in a series of papers from 1991 to 1998 in the Proceedings of ICCF-2<sup>62</sup>, ICCF-3<sup>63</sup>, ICCF-4<sup>64</sup> and ICCF-7<sup>65</sup>, an American Institute of Physics Conference Proceedings<sup>66</sup> and a Los Alamos report<sup>67</sup>.

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<sup>62</sup> T. N. Claytor, D.G. Tuggle, and H.O. Menlove, "Tritium Generation and Neutron Measurements in Pd-Si under High Deuterium Gas Pressure", in Second Annual Conference on Cold Fusion, "The Science of Cold Fusion". T. Bressani, E. Del Giudice and G. Preparata (Editors), Como, Italy, Societa Italiana di Fisica, Bologna, Italy (1991).

<sup>63</sup> T. N. Claytor, D.G. Tuggle, and S.F. Taylor. "Evolution of Tritium from Deuterided Palladium Subject to High Electrical Currents" in Third International Conference on Cold Fusion, "Frontiers of Cold Fusion", H. Ikegami (Editor) Universal Academy Press, Inc., Tokyo, Japan, pp. 217-229 (1992).

The Proceedings of ICCF-4 were published by a refereed journal. The LANL paper<sup>64</sup> described measurements of tritium from a glow discharge experiment, which were done in two ways. The plasma cell contained a palladium wire in a low-pressure deuterium atmosphere that was 99.995% pure. Application of a DC voltage produced the glow discharge. The deuterium gas was in a closed flow system with an in-line tritium gauge made by Femtotech. It was possible to extract the gas from the loop and oxidize it. Then, the resulting heavy water could be measured by a scintillation apparatus. Quoting the authors:

Small diameter wires (100 - 250 microns) have been used with gas pressures above 200 torr at voltages and currents of about 2000 V at 3-5 A. By carefully controlling the sputtering rate of the wire, runs have been extended to hundreds of hours allowing a significant amount ( $> 10^7$  nCi) of tritium to accumulate. We will show tritium generation rates for deuterium-palladium foreground runs that are up to 25 times larger than hydrogen-palladium control experiments using materials from the same batch.

The apparatus used in this research is shown in Figure 11<sup>64</sup>. The loop for continuous flow of the deuterium gas is in the top of the figure. The equipment for extraction and oxidation of the gas is in the bottom part of the figure. That is how it was possible to measure the tritium generated by LENR in two ways. The paper reports:

A hydrogen oxidation system was built as a backup test for tritium using a scintillation counter (Packard 1600). Calibration  $D_2$  gas with 25 nCi/l of tritium was used to test the two Femtotechs and the oxidation system. The two ionization systems agree to within 5% of each other while the scintillation results are within the experimental error (0.3 nCi) of the Femtotechs.

The agreement between the two methods of measuring tritium is very significant. This paper contains some of the best evidence for the production of tritium in LENR experiments.

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<sup>64</sup> D. G. Tuggle, D.G., T.N. Claytor, and S.F. Taylor, "Tritium Evolution from Various Morphologies of Palladium", in Fourth International Conference on Cold Fusion. 1993. Lahaina, Maui, Electric Power Research Institute 3412 Hillview Ave., Palo Alto, CA 94304 and Transactions of Fusion Technology, vol. 26, pp. 221-231 (1994) .

<sup>65</sup> T. N. Claytor, *et al.*, "Tritium Production from Palladium Alloys", in The Seventh International Conference on Cold Fusion, Vancouver, Canada, ENCO, Inc., Salt Lake City, UT. (1998).

<sup>66</sup> T. N. Claytor, D. G. Tuggle and H. O. Menlove, "Tritium Generation and Neutron Measurements in Pd-Si under High Deuterium Gas Pressure", American Institute of Physics Conference Proceedings 228, S. E. Jones, F. Scaramuzzi and D. Worledge (Editors) pp.467-480 (1991).

<sup>67</sup> T. N. Claytor, D. D. Jackson and D. G. Tuggle, "Tritium Production from a Low Voltage Deuterium Discharge on Palladium and Other Metals", Los Alamos National Laboratory Report LAUR#95-2687 (1996).

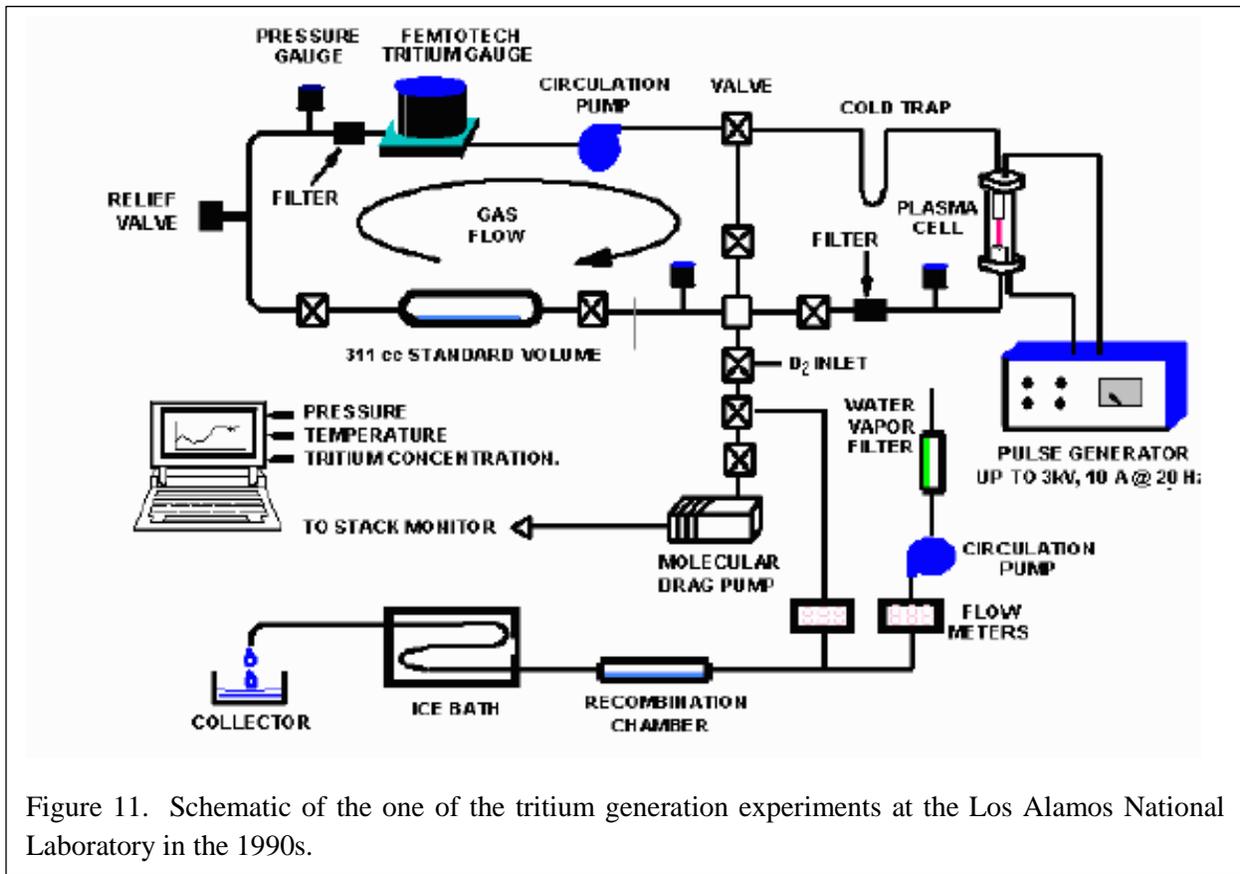


Figure 11. Schematic of the one of the tritium generation experiments at the Los Alamos National Laboratory in the 1990s.

The robust character of the evidence for tritium production in the Los Alamos experiments can also be appreciated by examination of the time history of the tritium concentration, as shown in Figure 12<sup>64</sup>. The scientists at LANL made runs with many variations of the materials and geometries: “A total of 65 plasma wire experiments were performed, 12 of these were other than palladium wire and plate. Twenty experiments were run with multiple wires, usually 3 wires bundled together, and eight experiments used different thickness foils 25 to 125 microns thick. The other tests were done with one 250 micron diameter wire and a 250 micron thick plate.” As shown in Figure 12, some of the runs did not produce tritium. However, other runs generated amounts of tritium far in excess of the runs with no tritium production. Those runs had signal-to-noise ratios much greater than both the scatter in the data and what amounted to blank runs without tritium production.

The experimental setup show in Figure 11 is a good example of the care taken in designing, testing, calibrating and operating LENR experiments. Such sophistication is not rare in the field. It should be noted again that capable scientists in a major laboratory did such careful work, which produced solid evidence of the ability of some LENR experiments to produce tritium. Again, tritium can only be produced by nuclear reactions.

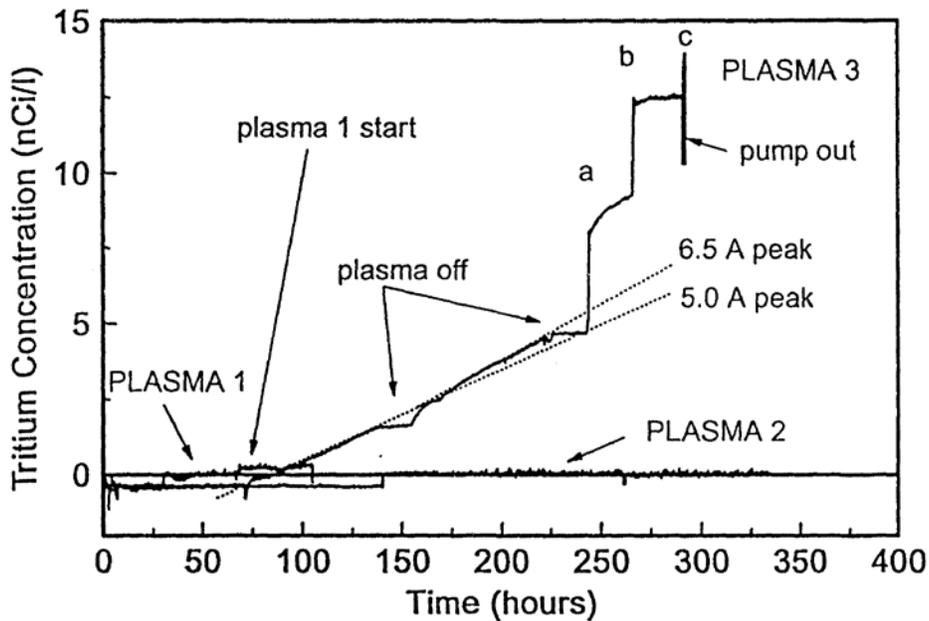


Figure 12. Temporal variation of the tritium signals for runs at the Los Alamos National Laboratory that did or did not produce tritium. It is seen that changes in the experiment produced changes in the tritium production rate for Plasma 3. The labels a, b and c refer to times when part of the system was flushed, releasing tritium that had been captured on surfaces.

(5) Bhabha Atomic Research Center (BARC)

BARC was founded in 1954 and is India's premier nuclear research facility<sup>68</sup>. Dozens of BARC scientists started experiments almost immediately after the March 1989 announcement by Fleischmann and Pons. The Director of BARC at that time later published a 94 page paper in a referred Journal in 1990 with 49 coauthors<sup>69</sup>. The early studies in BARC used Pd, Ti and Ni with both hydrogen and deuterium in electrolytic, gas, plasma and beam experiments, some of which had tritium and neutron monitors. The goal was to establish the nuclear nature of cold fusion. Mahadeva Srinivasan, who was then the leader of the Neutron Physics Division of BARC, has continued to participate in LENR conferences and produce papers on the early work at BARC. He presented papers involving tritium at an American Institute of Physics Conference<sup>70</sup>, ICCF-3<sup>71</sup>, ICCF-5<sup>72</sup>, ICCF-15<sup>73</sup> and ICCF-18<sup>74</sup>.

<sup>68</sup> [https://en.wikipedia.org/wiki/Bhabha\\_Atomic\\_Research\\_Centre](https://en.wikipedia.org/wiki/Bhabha_Atomic_Research_Centre).

<sup>69</sup> P. K. Iyengar *et al.*, "Bhabha Atomic Research Center Studies in Cold Fusion", Fusion Technology, vol. 18, pp. 32-94 (1991). Also, P. K. Iyengar and M. Srinivasan, "Overview of BARC Studies in Cold Fusion", Proc of the First Annual Conference on Cold Fusion, pp. 62-81, National Cold Fusion Institute (1991).

<sup>70</sup> M. Srinivasan *et al.*, "Observation of Tritium in Gas/Plasma Loaded Titanium Samples", Proc of Conf. on Anomalous Effects in Deuterium/Solid Systems, Edited by S. E. Jones, F. Scaramuzzi and D. Worledge, AIP Conference Proceedings vol. 228, pp. 514-534 (1991).

<sup>71</sup> M. Srinivasan *et al.*, "Tritium and Excess Heat Generation during Electrolysis of Aqueous Solutions of Alkali Salts with Nickel Cathode", in Frontiers of Cold Fusion, Edited by K. Ikegama, pp. 123-138, Universal Academic Press, Inc., Tokyo (1993).

The presentation by Srinivasan at ICCF-18 gave details on the experiments and tritium measurements conducted at BARC in the first two years after the Fleischmann-Pons announcement. Eight heavy water electrolysis experiments in six divisions of BARC, with Pd, Pd-Ag and Ti cathodes, produced both tritium and low levels of neutrons. Great care was made for the scintillation measurements of the tritium, which included using depleted vials and permitting chemiluminescence to die out prior to making recordings. Levels of tritium, as much as 20,000 times the initial levels from the heavy water, were measured. The BARC group also measured tritium produced from electrolytic cells with nickel cathodes and light water electrolytes, and from self-heated nickel wires in atmospheres of hydrogen gas. A useful compilation of LENR publications from BARC is on the web<sup>75</sup>.

As is the case with other reports of tritium production in LENR experiments reviewed above, the high quality of the scientists and the work on tritium production at BARC should be appreciated.

#### (6) Reports of Tritium Production from Other Laboratories

Research on the generation of tritium reviewed above was generally done by significant groups, some in major laboratories and some with sustained programs. There have been many other reports of tritium production in LENR experiments, as already noted in the quotation from Bockris. One of them will be mentioned next, and then references will be made to a review and to compilations of LENR experiments that resulted in tritium production.

A team of nine researchers from Energetics Technologies in Israel performed LENR experiments using pulsed and ultrasonic excitation of cells with Pd cathodes in heavy water electrolytes, as described above<sup>41</sup>. In one run, they measured thermal energy output that was 26 times the electrical energy input. That result was discussed in Section 5 and shown in Figure 8. The electrolyte from that experiment was measured by a national laboratory in Italy. The measured tritium level was 2.5 times the background level. Making corrections due to addition of make-up heavy water during the experiment increased the ratio to 7.5. But, even without the correction, it is clear that the experiment produced tritium, as well as a large amount of excess heat.

During ICCF-14, Biberian reviewed the many products that resulted from LENR gas loading experiments<sup>76</sup>. He wrote the following about tritium production from such experiments. His paper contains references to the work he reviewed.

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<sup>72</sup> T. K. Sankaranarayanan *et al.*, "Evidence for Tritium Generation in Self-Heated Nickel Wires Subjected to Hydrogen Gas Absorption/Desorption Cycles", Proc. Fifth Int'l. Conference on Cold Fusion, pp. 173-179 (1995).

<sup>73</sup> M. Srinivasan, "Hot Spots, Chain Events and Micro-Nuclear Explosions", Proc. ICCF-15, pp. 240-245 (2009).

<sup>74</sup> M. Srinivasan, "Revisiting the Early BARC Tritium Results", J. Condensed Matter Nuclear Science, vol. 15, pp. 137-148 (2015).

<sup>75</sup> [http://lenr-canr.org/wordpress/?page\\_id=463](http://lenr-canr.org/wordpress/?page_id=463)

<sup>76</sup> J.-P Biberian, "Cold Fusion by Gas Loading: A Review", Proceedings of the 14<sup>th</sup> International Conference on Condensed Matter Nuclear Science, D. J. Nagel and M. E. Melich (Editors), pp. 370-384 (2008) ISBN 978-0-578-06694-0. <http://www.iscmns.org/iccf14/ProcICCF14a.pdf>

As early as 1990, Iyengar *et al.*, Srinivasan *et al.*, Iyengar *et al.*, Kauskik *et al.*, and Rout *et al.* have shown production of tritium in palladium and titanium samples loaded with deuterium. Lamza *et al.* measured tritium in various metals loaded with deuterium. De Nino *et al.* detected tritium in titanium loaded with deuterium. Yamada *et al.* have shown the production of tritium when deuterium is pumped out of a palladium foil covered on one side with MnOx. Narita *et al.* have observed mass three corresponding either to tritium or helium-3 when hydrogen is pumped out of a palladium foil covered on one side with MnOx or gold. Similarly, Wei *et al.* have also observed mass three when deuterium flows through a palladium foil. Claytor *et al.* measured tritium with Pd-Si electrodes in deuterium gas. Clarke *et al.* detected tritium in titanium loaded with deuterium and later observed production of tritium in a cell similar to the one of Arata. Romodanov *et al.* have also detected tritium. Lipson *et al.* detected significant amounts of tritium when cooling  $\text{YBa}_2\text{Cu}_3\text{O}_7\text{D}_x$  to its Curie temperature in deuterium gas.

Two authors have provided information, references and compilations of papers on tritium from many other LENR experiments. Kozima's first book reviews papers on tritium production<sup>77</sup>. Storms' first book lists 65 papers from LENR experiments, which report tritium production<sup>78</sup>.

#### (7) Conclusion Regarding Tritium Production

Tritium has numerous uses<sup>49</sup>. It remains to be seen if LENR will prove to be a practical technology to generate tritium for any of the applications. Capturing tritium produced in LENR energy generators would be a major engineering challenge.

Whatever the future, it is widely accepted now by persons familiar with the relevant literature that tritium can be produced in LENR experiments. This is due to the existence of many strong reports by competent scientists of the generation of tritium in such experiments. Tritium cannot be produced by chemical reactions. Hence, LENR do, indeed, involve nuclear reactions. LENR are definitely operable.

## 7. Helium Production Measurements

Helium is the second element in the periodic table, so its nucleus has two protons. The number of neutrons in a helium nucleus can vary from zero to eight, but the isotopes with one or two neutrons ( $^3\text{He}$  and  $^4\text{He}$ ) are the only stable (non-radioactive) forms<sup>79</sup>. There is one atom of  $^3\text{He}$

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<sup>77</sup> H. Kozima, "Discovery of the Cold Fusion Phenomenon", pp. 74-86, Ohtake Shuppan (1998).

<sup>78</sup> E. Storms, "The Science of Low Energy Nuclear Reaction", pp.79-81, World Scientific (2007).

<sup>79</sup> [https://en.wikipedia.org/wiki/Isotopes\\_of\\_helium](https://en.wikipedia.org/wiki/Isotopes_of_helium).

for every million atoms of  $^4\text{He}$  in air. The nucleus of  $^4\text{He}$  is also called an alpha particle<sup>80</sup>, which is sometimes emitted with various kinetic energies from nuclear reactions or during alpha decay of radioactive isotopes<sup>81</sup>.

There are three primary challenges to measuring the production of helium in LENR experiments. First, helium is not as easy to measure as tritium, simply because it is not radioactive. Sophisticated mass spectrometry system must be employed<sup>82</sup>. The instruments must have resolution high enough to distinguish between  $^4\text{He}$  and a  $\text{D}_2$  molecule. Both of those entities have two protons and two deuterons, so their masses are similar.  $^4\text{He}$  is 4.0026032 AMU<sup>79</sup> and  $\text{D}_2$  is 4.028204 AMU<sup>83</sup>. It is possible to excite helium and use its optical emission to quantify its concentration. That method is little used, however, because it also requires very good and well calibrated instrumentation. And, it is more complex than mass spectrometry to convert measured intensities into absolute concentrations.

The second challenge has another contrast with tritium. While environmental levels of tritium are negligibly low compared to levels produced in LENR experiments,  $^4\text{He}$  is in the atmosphere at the level of 5.2 ppm<sup>84</sup>. Only a few LENR experiments have produced concentrations of helium in excess of this level. One will be noted below. Hence, there has been concern that atmospheric helium could possibly enter LENR experiments. That is, whether the helium measured after LENR experiments is due to nuclear reactions or atmospheric contamination has been an issue. Careful laboratory work, however, has eliminated the possibility of contamination from the air.

The third issue with helium measurements is due to the fact that diffusion of helium is not as rapid through metals as the diffusion of the isotopes of hydrogen. This is simply due to the fact that the helium nucleus carries with it orbital electrons, unlike the hydrogen isotopes. Hence, helium is much larger and diffuses more slowly. If helium is produced in the bulk of a palladium cathode loaded with deuterium, some of it will tend to remain in the metal. This has required sectioning of cathodes and heating them to remove produced helium.

Helium can be measured in LENR experiments independent of whether or not heat production is measured. Although it became known experimentally that LENR are not conventional D-D fusion events, as in Table 1, there has still been much interest in the possible correlation of helium generation to heat production. This interest is traceable, again, to the question of which specific nuclear reactions occur during LENR. Storms harvested data from many LENR reports

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<sup>80</sup> [https://en.wikipedia.org/wiki/Alpha\\_particle](https://en.wikipedia.org/wiki/Alpha_particle).

<sup>81</sup> [https://en.wikipedia.org/wiki/Alpha\\_decay](https://en.wikipedia.org/wiki/Alpha_decay).

<sup>82</sup> <http://rpl.pnnl.gov/capabilities/helium.stm>.

<sup>83</sup> <https://en.wikipedia.org/wiki/Deuterium>.

<sup>84</sup> <https://en.wikipedia.org/wiki/Helium>.

that provided information on the production both helium and heat in the same experiments<sup>85</sup>. The results are plotted in Figure 13 as a histogram of the reported ratios of helium to heat<sup>32</sup>.

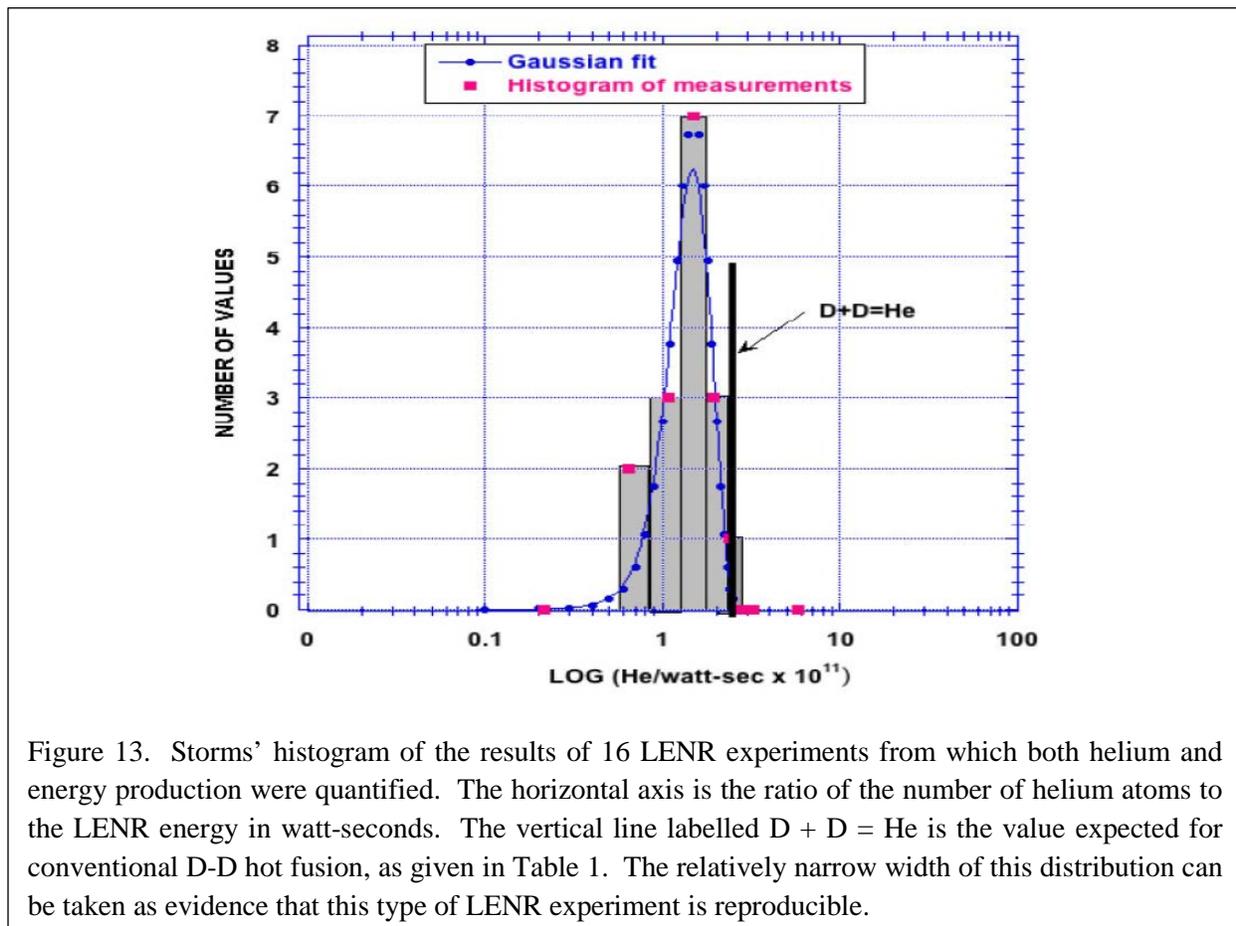


Figure 13. Storms' histogram of the results of 16 LENR experiments from which both helium and energy production were quantified. The horizontal axis is the ratio of the number of helium atoms to the LENR energy in watt-seconds. The vertical line labelled  $D + D = He$  is the value expected for conventional D-D hot fusion, as given in Table 1. The relatively narrow width of this distribution can be taken as evidence that this type of LENR experiment is reproducible.

A short review paper on the production of helium in LENR experiments was published last year in a prestigious Indian journal<sup>86</sup>. A recent and thorough review of helium production in LENR experiments is in the second book by Storms<sup>87</sup>. The papers cited below are actually a small fraction of those examined by Storms. Recall that the purpose of this document is to provide some strong evidence that operative LENR devices are capable of producing energy and products, such as tritium or helium. This does not have to be a comprehensive review in order to provide convincing evidence of the operability and utility of LENR.

The papers on helium production reviewed below are organized by the laboratories that did the research. Some of the papers noted in the following review deal solely with helium detection,

<sup>85</sup> E. Storms, "Status of Cold Fusion", *Naturwissenschaften* (2010) 97:861–881.

<sup>86</sup> A. ul-Rahman Lomax, "Replicable Cold Fusion Experiment: Heat/Helium Ratio", *Current Science*, vol. 108, pp. 574-577 (2015).

<sup>87</sup> E. Storms, "The Explanation of Low Energy Nuclear Reaction", pp. 23-43, Infinite Energy Press, Concord NH (2014).

while others also report on correlations between helium production and heat generation. The global character of early helium measurements is worth noting. The papers discussed below were written by researchers in the U.S., Italy and Japan.

(1) Naval Air Warfare Center

The first simultaneous measurements of helium and heat production were made by a team lead by Miles in the U. S. Naval Air Warfare Center in China Lake CA<sup>88</sup>. The work attracted much attention for two reasons. First, the ratio of the two measured values was close to the 23.8 MeV of the gamma ray, which is emitted in the rare instances when ordinary D-D fusion results in production of helium. Second, the experiments were conducted using glass containers that were permeable to helium. Critics were concerned that the low levels of measured helium were due to leakage into the glass containers from the 5.2 ppm of helium in the atmosphere. Miles and Bush later used impervious metal containers to rule out atmospheric contamination. They still obtained a correlation between helium and heat.<sup>89</sup>

In 2003, Miles provided a review of his three sets of measurements of heat and helium in Pd-D electrochemical LENR experiments<sup>90</sup>. The abstract of the paper reads as follows (the word “enthalpy” means “energy”): “A correlation between excess enthalpy and excess helium-4 was measured in 18 out of 21 experiments. The observation of no excess enthalpy was correlated with no excess helium in 12 out of 12 experiments”. Miles provided reasons that the three experiments failed to produce correlations. He went further to state in the text of the paper that “An exact statistical treatment shows that the probability is only one in 750,000 that the China Lake set of heat and helium measurements could be that well correlated due to random experimental errors”.

(2) Università di Roma La Sapienza and Istituto Superiore di Sanità

Gozzi and numerous colleagues from laboratories in Rome performed LENR experiments that produced helium, and reported the results in six papers during the period 1993-1998. Only the last of these papers will be reviewed here. With seven coworkers, Gozzi measured helium, heat and x-rays from a cell that was connected to an on-line system for helium determination<sup>91</sup>. Figure 14 gives some of their time histories of input and excess powers and measured helium.

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<sup>88</sup> M. H. Miles *et al.*, “Correlation of Excess Power and Helium Production During D<sub>2</sub>O and H<sub>2</sub>O Electrolysis Using Palladium Cathodes”, *J. Electroanalytical Chemistry*, vol. 346, p. 99 (1993).

<sup>89</sup> M. H. Miles and B. F. Bush, “Heat and Helium Measurements in Deuterated Palladium”, *Transactions of Fusion Technology*, vol. 26 (4T), pp. 156-159 (1994).

<sup>90</sup> M. H. Miles, “Correlation of Excess Enthalpy and Helium-4 Production: A Review”, in *Proc of the 10<sup>th</sup> Intl. Conference on Condensed Matter Nuclear Science*, P. L. Hagelstein and S. R. Chubb (Editors), pp. 123-131, World Scientific (2006).

<sup>91</sup> D. Gozzi *et al.*, “X-Ray, Heat Excess and <sup>4</sup>He in the D/Pd System”, *J. of Electroanalytical Chemistry*, vol. 452, pp 253-271 (1998).

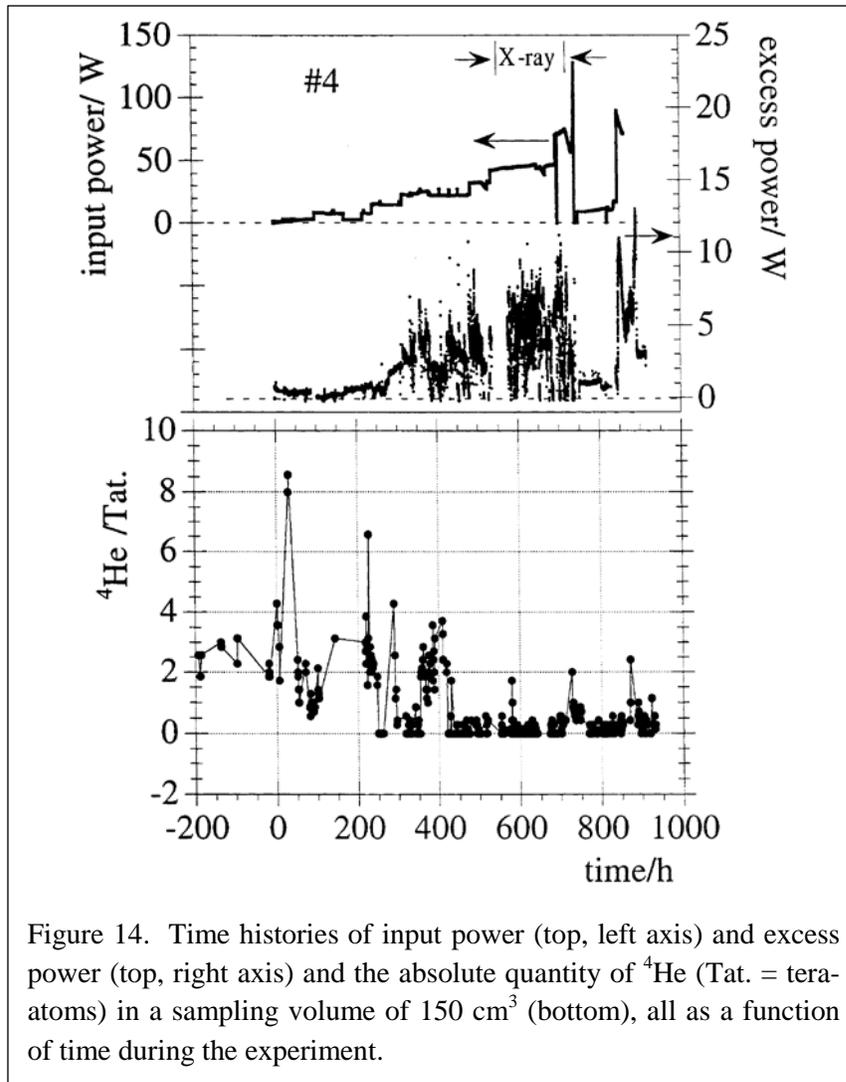


Figure 14. Time histories of input power (top, left axis) and excess power (top, right axis) and the absolute quantity of <sup>4</sup>He (Tat. = tera-atoms) in a sampling volume of 150 cm<sup>3</sup> (bottom), all as a function of time during the experiment.

There is no clear correlation between production of heat and helium in these data. The authors note, however “....it is important to remember that since the <sup>4</sup>He measurement is not performed in continuous mode, as is the heat power excess, a significant volume of the electrolysis gas mixture is lost without being analysed.” Their data show strong, albeit erratic evidence for the production of both heat and helium.

It is noted by Gozzi *et al.* in this 1998 paper that, in less than a decade after the Fleischmann-Pons announcement, 21 conference proceedings had been published and 200 patents had been issued. Those figures, and the information provided above in Section 3, show that there is ample available experimental information on the characteristics of LENR.

### (3) SRI International

McKubre and other SRI International scientists in Palo Alto CA were among the first to respond to the Fleischmann-Pons announcement with a laboratory program. They have had a high level of effort on LENR experiments, sponsored by many organizations, continuously for the past 28 years. Approximately 20 people have worked on LENR in that laboratory<sup>92</sup>. Many important experimental results came out of their research. Some of their early heat production data was presented and discussed in Section 5. Here we concentrate on an experiment reported in 2000, which involved both helium and heat production.

Figure 15 from SRI's research shows the time history of helium generation and its correlation with the recorded heat<sup>93</sup>. The helium levels that were measured exceeded the atmospheric level of 5.2 ppm. Contamination from the air, therefore, could not have produced the data in Figure 15. Those data received a lot of attention for three reasons: (a) they were acquired and analyzed by a team of very capable scientists, (b) it was and remains the most detailed correlation of

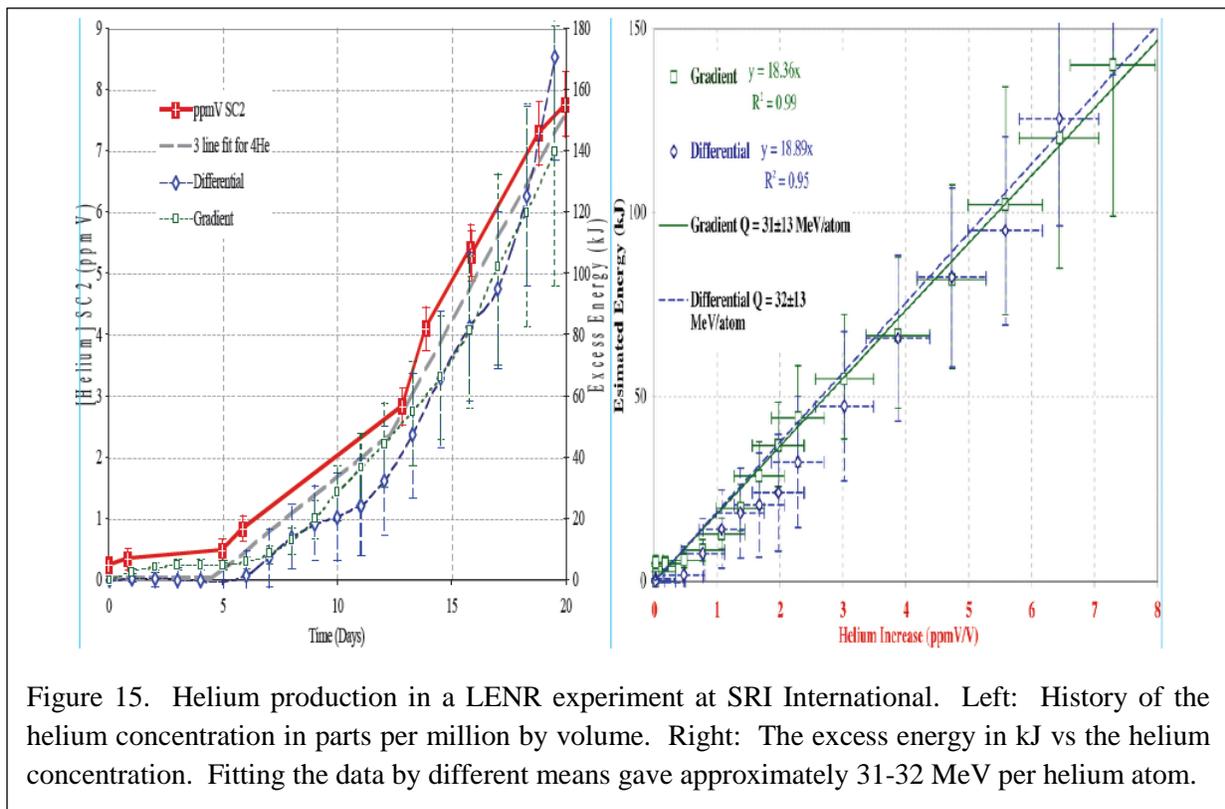


Figure 15. Helium production in a LENR experiment at SRI International. Left: History of the helium concentration in parts per million by volume. Right: The excess energy in kJ vs the helium concentration. Fitting the data by different means gave approximately 31-32 MeV per helium atom.

<sup>92</sup> M. C. H. McKubre *et al.*, “Can LENR Provide Cheap and Clean Energy?”, Oslo (2014) Click on “Presentation slides are here” at <https://coldfusionnow.org/tag/norway/> and <http://www.infinite-energy.com/iemagazine/issue119/norway.html>.

<sup>93</sup> M. C. H. McKubre *et al.*, “The Emergence of a Coherent Explanation for Anomalies Observed in D/Pd and H/Pd Systems: Evidence for <sup>4</sup>He and <sup>3</sup>He Production”, Proceedings of the Eighth International Conference on Cold Fusion, F. Scaramuzzi (Editor), Italian Physical Society, Bologna, pp. 3-10 (2000).

helium and heat production, and (c) the correlation gave values of 31 and 32 MeV, in excess of, but not far from, the 23.8 MeV in the helium production branch of conventional D-D fusion. It was thought that some of the helium produced in the experiment might have been retained in the Pd material and not measured. That could account for the higher ratio of energy to atoms if, indeed, 23.8 MeV were released per production of one helium atom, as in the low probability branch of conventional D-D fusion noted in Table 1.

Many scientists and interested people took the helium-heat correlation in figure 15 as evidence of some type of D-D fusion process. But, it was not necessarily conventional D-D fusion, as in hot plasma and energetic beam experiments. The products and probabilities given in Table 1 for hot D-D fusion were not seen in this and other LENR experiments. It is of great significance that helium and heat were both produced and are correlated in several LENR experiments. But, that can occur by reaction pathways other than conventional fusion.

#### (4) Osaka University

Arata and Zhang at the Osaka University published over 40 papers on the results of LENR experiments in the two decades from 1990 to 2010<sup>94</sup>. They introduced some experimental innovations, including the use of uncoated and coated nanometer-scale powders, and an electrochemical cathode that was hollow in the center to produce pure D<sub>2</sub> gas at high pressures. That device was called the “Double Structure” (DS) cathode. Their heat measurements were discussed in Section 5. Here we focus on their many measurements of helium production, as reported in three papers in the mid-to-late 1990s

The first Arata-Zhang paper<sup>95</sup> on helium generation in 1995 demonstrated that their mass spectrometer had sufficient resolution to distinguish <sup>4</sup>He from D<sub>2</sub>. After energy production experiments, they heated the palladium nano-powders that were inside of the DS Cathode during the runs to release helium from the powders. Mass spectra of the evolved gas were taken repeatedly. Levels of helium well above the measurement noise were recorded. The authors stated in this paper “These results were found to be fully reproducible”.

Results of similar measurements were reported in a 1996 paper by these scientists<sup>96</sup>. Figure 16 shows one of their data sets for a run with a sample that was not deuterated and two other runs that had high levels of deuterium loading during the heat production experiments. In the non-deuterated sample, there were no peaks from either <sup>4</sup>He or D<sub>2</sub>. Separate peaks from those entities were detected in each of the two deuterated samples. Details on the temperature-time histories

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<sup>94</sup> Go to <http://lenr-canr.org/index/menu/menu.php> and search with “arata”.

<sup>95</sup> Y. Arata and Y.-C. Zhang, “Advancement of Solid State Plasma Fusion (“Cold Fusion”), Proc. Japanese Academy, vol. 71 Ser. B, pp. 304-309 (1995).

<sup>96</sup> Y. Arata and Y.-C. Zhang, “Deuterium Nuclear Reaction Processes within Solid”, Proc. Japanese Academy, vol. 72 Ser. B, pp. 179-184 (1996).

for the heating during these mass measurements are in the paper. The third Arata-Zhang paper on helium production in 1999 used a different mass spectrometry method, and provided added evidence of their ability to generate helium in LENR experiments<sup>97</sup>.

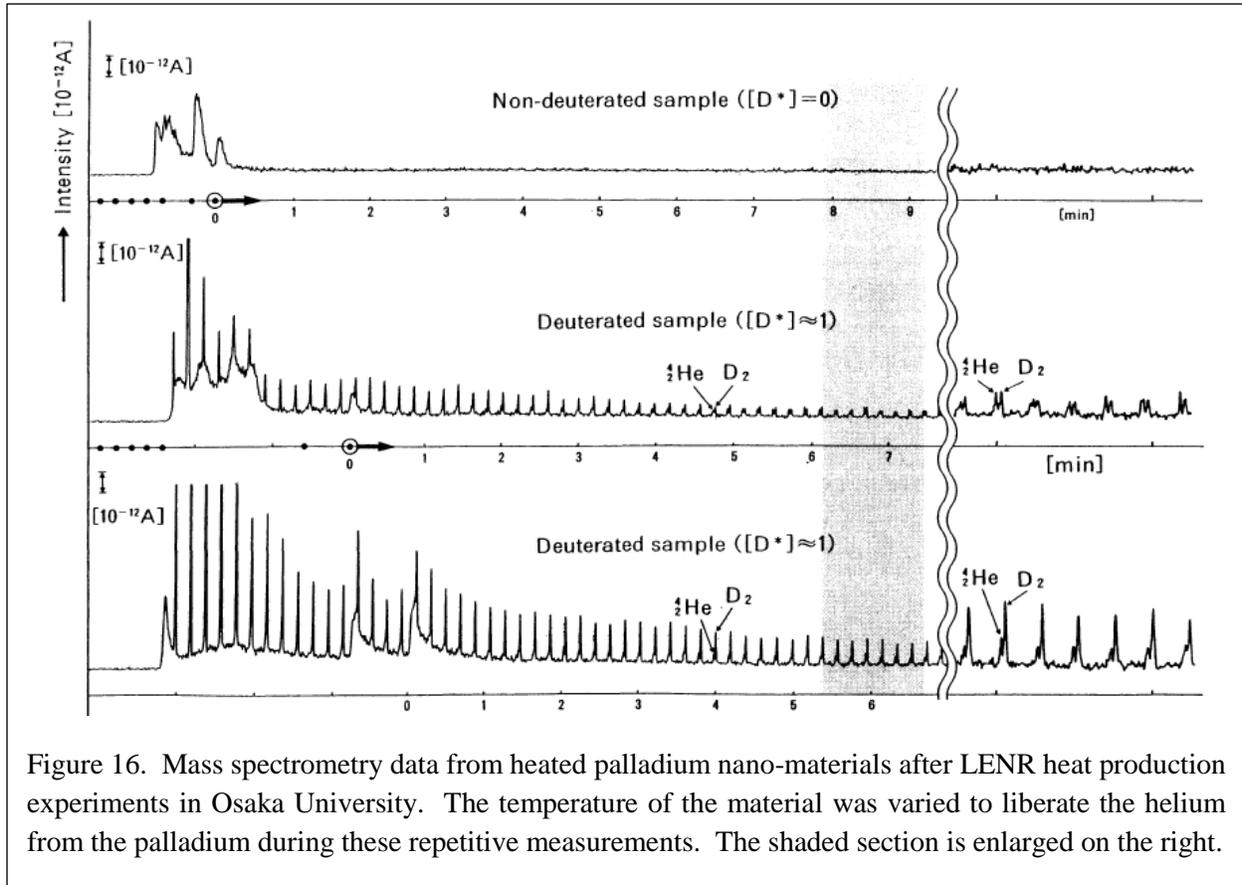


Figure 16. Mass spectrometry data from heated palladium nano-materials after LENR heat production experiments in Osaka University. The temperature of the material was varied to liberate the helium from the palladium during these repetitive measurements. The shaded section is enlarged on the right.

### (5) Other Reports on Helium Production

There have been many other reports of helium production in LENR experiments. We make brief mention of one of them in the next paragraph. The second book by Storms has short summaries of more reports of helium production<sup>87</sup>.

E. Yamaguchi and his team in the NTT Basic Research Laboratories produced three papers on helium production in the early 1990s. In one of them<sup>98</sup>, their conclusion section read: “We have for the first time succeeded in detecting <sup>4</sup>He production ‘in situ’ and with high reproducibility. ....The amount of <sup>4</sup>He gas produced was closely correlated to the evolution of excess heat.....”

<sup>97</sup> Y. Arata and Y.-C. Zhang, “Anomalous Production of Gaseous <sup>4</sup>He at the Inside of “DS Cathode” During D<sub>2</sub>O Electrolysis”, Proc. Japanese Academy, vol. 75 Ser. B, pp. 281-286 (1999).

<sup>98</sup> E. Yamaguchi and T. Nishioka, “Direct Evidence for Nuclear Fusion Reactions in Deuterated Palladium”, Frontiers of Cold Fusion, H. Ikegama (Editor), pp. 179-188, Universal Academy Press (1993).

## (6) Conclusion Regarding Helium Production

There are many uses for helium, and associated concerns about the availability of enough helium to satisfy various applications in the future<sup>84</sup>. It is conceivable that the production of helium in LENR energy generators will prove to be practically important. That is, when helium is a common byproduct of heat generation, it might be harvested. However, systems to do so would be challenging to develop and operate.

Some scientific discussions about production of helium in LENR experiments still continue. They center mainly on the mechanism for helium production, and not on the quality of the data for such generation. There are many strong reports of the generation of helium in LENR experiments performed by competent scientists. Helium cannot be produced by chemical reactions. Hence, LENR do, indeed, involve nuclear reactions. Operability of LENR is again demonstrated.

## 8. Production of Other Elements in LENR Experiments

The material above on LENR products focused on tritium and helium generation because the evidence for those products is voluminous and strong. There are also many reports on the production of other elements and isotopes from LENR experiments. Experiments performed by good researchers showed that there can be increases in the concentrations of elements across most of the periodic table. The increases have been attributed to LENR. Such processes are called transmutations. There are useful reviews of evidence for nuclear transmutations in LENR experiments. Both books by Kozima have sections on this topic<sup>99,100</sup>. Storms' two books on LENR review experimental evidence for transmutations. His first book has a table summarizing the results of dozens of reports on transmutations<sup>101</sup>. The second volume also has extensive information on such results of LENR experiments<sup>102</sup>. A comprehensive 2011 review of transmutation data from diverse experiments is also available<sup>103</sup>.

Two reports on transmutations across much of the periodic table are now reviewed in some detail. They involved very different experiments, but produced similar results. Figure 17 gives data from both of those experiments as a function of atomic mass number (A).

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<sup>99</sup> H. Kozima, "Discovery of the Cold Fusion Phenomenon", pp. 109-128, Ohtake Shuppan (1998).

<sup>100</sup> H. Kozima, "The Science of the Cold Fusion Phenomenon", pp. 35-46, Elsevier (2006).

<sup>101</sup> E. Storms, "The Science of Low Energy Nuclear Reaction", pp. 93-95, World Scientific (2007).

<sup>102</sup> E. Storms, "The Explanation of Low Energy Nuclear Reaction", pp. 43-73, Infinite Energy Press (2014).

<sup>103</sup> M. Srinivasan, G. Miley and E. Storms, "Low Energy Nuclear Reactions: Transmutations", in the Nuclear Energy Encyclopedia, S. B. Krivit, J. H Lehr and T. B. Kingery (Editors), pp. 503-539, Wiley (2011).

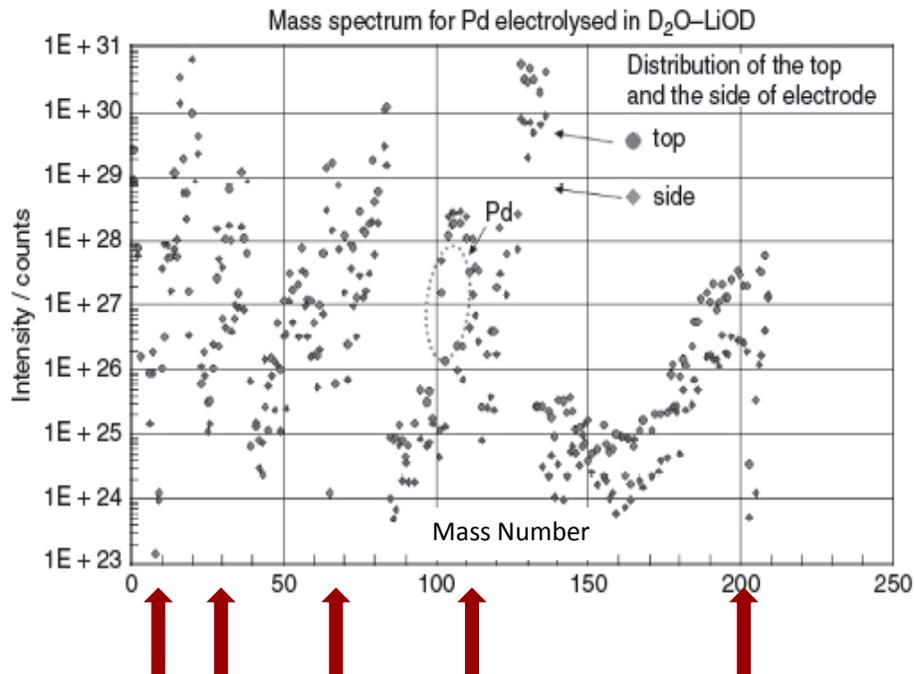
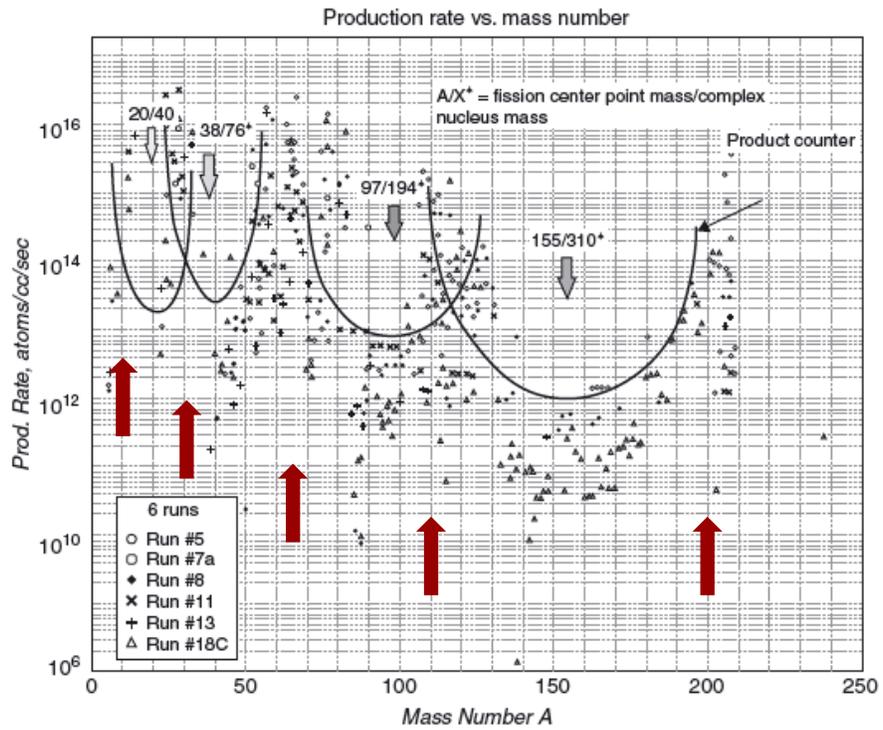


Figure 17. Top: Transmutation data from Miley *et al.* Bottom: Transmutation data from Mizuno *et al.* The arrows indicating mass numbers for peaks are at the same mass numbers for both data sets.

Miley and his colleagues in Illinois published data from a unique LENR experiment<sup>104</sup>. They electrolyzed plastic beads coated with Pd and Ni in a packed bed configuration through which a light water (H<sub>2</sub>O) electrolyte circulated. They used four analytical techniques, Secondary Ion Mass Spectrometry, Auger Electron Spectroscopy, Energy Dispersive X-Ray Spectroscopy and Neutron Activation Analyses, some both before and after 14 day runs. Their production rate data (atoms/cm<sup>3</sup>/sec) are shown in Figure 16 as a function of atomic mass number.

Mizuno and his collaborators in Hokkaido presented results from another unusual LENR experiment<sup>105</sup>. They electrolyzed a Pd rod in a closed cell containing a heavy water (D<sub>2</sub>O) electrolyte at high pressures, temperatures and current densities for 32 days. They used the same analytical methods as Miley *et al.*, except Electron Probe Microanalysis was employed in place of Neutron Activation Analysis. Data were reported as count rates from Secondary Ion Mass Spectrometry, as shown in Figure 17, and grams of deposited material, both as a function of the atomic mass A. In addition, Miley *et al.* observed excess heat, and Mizuno *et al.* measured anomalous isotope ratios. Most importantly, the two data sets exhibited peaks in elemental production rates at similar values of atomic mass. The data sets from those two transmutation experiments and others were shown to be statistically correlated<sup>106</sup>.

Storms produced a histogram of the number of reports of the production of particular elements in LENR experiments, which is reproduced in Figure 18<sup>107</sup>. This compilation corroborates the data from Miley and Mizuno. The unexpected elements, which were reported most frequently, cluster near a few specific values of atomic number (mass). The basic reason for this behavior is not understood, despite an optical model calculation of how neutron wavelengths fit within nuclei of specific sizes<sup>108</sup>. The key issue with quantitative understanding of transmutation data is clear. Measurements of elemental production rates depend on four factors, the number of starting atoms of elements in the experimental materials, the reaction rates, the duration of experiments and the sensitivity of the instruments and techniques used for elemental quantification. Knowing only rates is insufficient to understand quantitatively what has been measured in LENR transmutation experiments.

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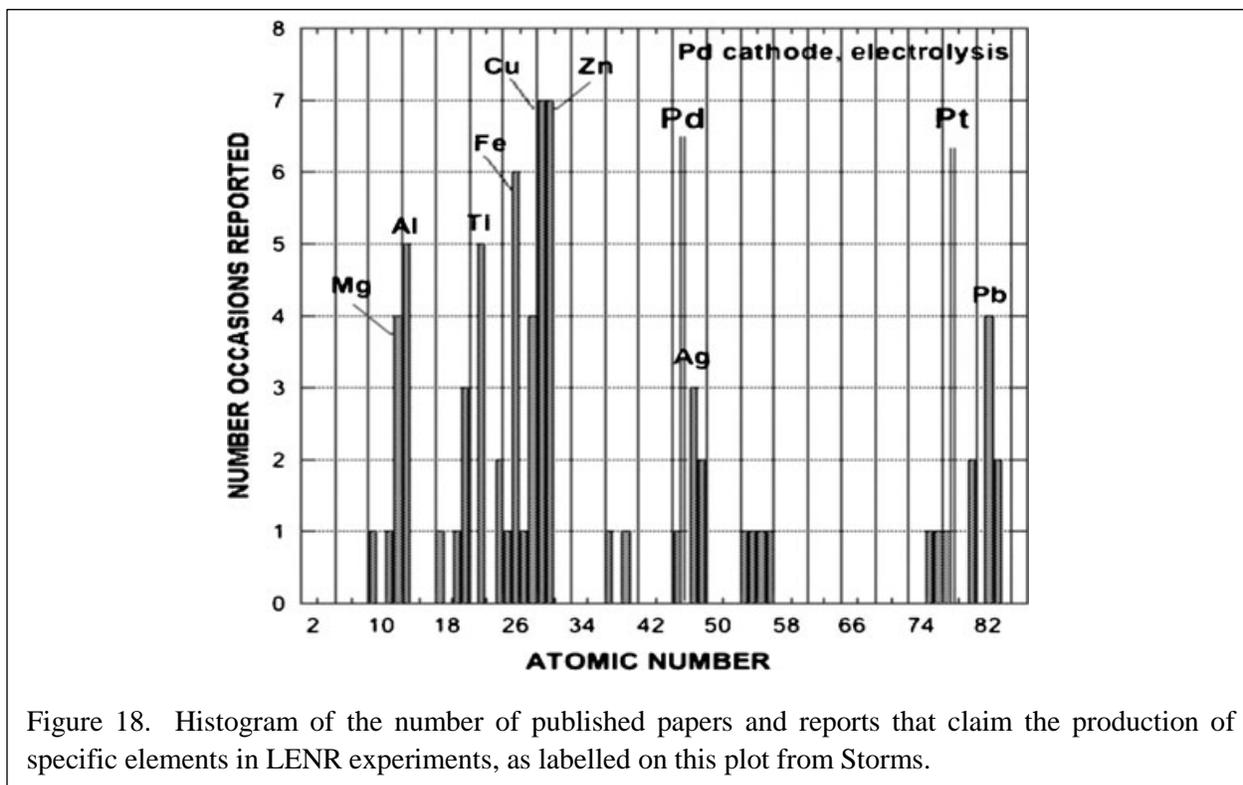
<sup>104</sup> G. H. Miley, "Possible evidence of anomalous energy effects in H/D-loaded solids – Low energy nuclear reactions (LENR)", *Journal of New Energy*, Vol 2(3-4), pp. 6-13 (1997) and G. H. Miley and J.A. Patterson, "Nuclear transmutations in Thin-Film Nickel Coatings Undergoing Electrolysis", *Journal of New Energy*, Vol 1 (3): pp. 5-13 (1996) and G. H. Miley "On the Reaction Product and Heat Correlation for LENRs", *Proc. of 8<sup>th</sup> International Conference on Cold Fusion*, F. Scaramuzzi (Editor), Lerici (La Spezia), Italy, pp. 419-424 (2000).

<sup>105</sup> T. Mizuno, T. Ohmori, and M. Enyo, "Isotopic Changes of the Reaction Products Induced by Cathodic Electrolysis in Pd", *Journal of New Energy*, vol. 1(3): pp. 31-45 (1996) and T. Mizuno, "Isotopic Changes of Elements Caused by Various Conditions of Electrolysis", 237th ACS National Meeting, Salt Lake City, UT (2009).

<sup>106</sup> F. Scholkmann and D. J. Nagel, "Statistical Analysis of Transmutation Data from Low-Energy Nuclear Reaction Experiments and Comparison with a Model-based Prediction of Widom and Larsen", *Journal of Condensed Matter Nuclear Science*, vol. 13, pp. 485-494 (2014).

<sup>107</sup> E. Storms, "The Science of Low Energy Nuclear Reaction", p. 96, World Scientific (2007).

<sup>108</sup> A. Widom and L. Larsen, "Nuclear Abundances in Metallic Hydride Electrodes of Electrolytic Chemical Cells", arXiv:cond-mat/0602472 (2006).



technical literature, which show LENR systems were able to produce energy and nuclear reaction products. These systems are, therefore, operable. For this reason, LENR technology is understood to be operable. Put bluntly, LENR can be made to occur. Their occurrence produces strong evidence of different types, which can be measured using demonstrated techniques.

This report has discussed several examples where the excess heat claimed by Fleischmann and Pons was able to be reproduced by their group and other research teams. The Fleischmann and Pons type of device is, therefore, operable. Utility of an "operable" LENR device is demonstrated when its design is subsequently used in the design of another "operable" LENR device. The Fleischmann and Pons device has utility, since its design was subsequently used in the design of other operable LENR devices by multiple researchers in several countries. The examples given in this report provide incontrovertible evidence of the utility of LENR systems.

This report cannot actually prove that there is a consensus of those skilled in the art concerning the existence of reputable evidence from LENR experiments, which support the claims of excess heat generation and the production of nuclear products. But, such a consensus exists, as indicated by the vast literature, numerous conferences and current efforts to commercialize LENR. It is emphasized, again, that the empirical LENR evidence cannot be explained by chemistry. It can only be rationalized by invoking nuclear processes. Incomplete understanding does not obviate, or even degrade, the volume or quality of the experimental evidence.

The reader of this report is asked to notice that most of the references cited in the text and the papers listed in the appendices are from refereed journals in the 1990s. That is, the evidence for LENR operability and utility has long been available. Ignorance of the large and strong body of literature remains the common reason in the U.S. for failing to recognize the scientific legitimacy and practical potential of LENR.

The study of LENR is currently a challenging scientific topic. However, LENR is stoutly established experimentally, as was superconductivity for the forty years before it was understood. Much scientific research is still needed to fully understand the LENR mechanisms. As was the case with the early transistors, the potential for LENR commercialization seems clear. Still, a great deal of development work will be needed to realize the commercial potential of LENR. Our comparison of LENR with superconductivity and transistors has two motivations. First, those are apt historical precedents for the current status of LENR research and on-going efforts toward commercialization. Second, LENR has the potential to be as important and impactful as are medical and other superconductivity systems, and as are transistor-enabled computations and communications. Energy from LENR could turn out to be transformational.

## **Acknowledgement**

M. C. H. McKubre and two reviewers provided useful comments, which are greatly appreciated.

## Appendix A. Selected Papers on Energy Production

M. Fleischmann and S. Pons, "Electrochemically Induced Nuclear Fusion of Deuterium", J. Electroanalytical Chemistry, vol. 261, pp. 301-307 (1989) and errata in Vol. 263.

M. C. H. McKubre *et al.*, "Excess Power Observations in Electrochemical Studies of the D/Pd System; the Influence of Loading", in Third International Conference on Cold Fusion, "Frontiers of Cold Fusion", H Ikegami (Editor), pp. 5-18, Universal Academy Press, Inc., Tokyo, Japan (1992)

K. Kunimatsu *et al.*, "Deuterium Loading Ratio and Excess Heat Generation during Electrolysis of Heavy Water in a Palladium Cathode in a Closed Cell Using a Partially Immersed Fuel Cell Cathode" in Third International Conference on Cold Fusion, "Frontiers of Cold Fusion", H. Ikegami (Editor), pp. 31-45, Universal Academy Press, Inc., Tokyo, Japan (1992)

M. Fleischmann and Pons, "Calorimetry of the Pd-D<sub>2</sub>O System: from Simplicity via Complications to Simplicity", Physics Letters A, vol. 176, pp. 118-129 (1993)

Y. Arata and Y.-C. Zhang, "Cold Fusion Reactions Driven by 'Lattice Quake'", Proc. Japan Academy, 71, Ser. B (1995)

D. Gozzi *et al.*, "Calorimetric and Nuclear Byproduct Measurements in Electrochemical Confinement of Deuterium in Palladium", J. Electroanalytical Chemistry, vol. 380, pp 91-107 (1995)

### Links to Fleischmann-Pons Energy Production Papers

A list of some Fleischmann-Pons papers with active links is below.  
Using Ctrl and left clicking on the links should bring up the papers.

Fleischmann, M., S. Pons, and M. Hawkins, "Electrochemically induced nuclear fusion of deuterium", (1989), [lenr-canr.org/acrobat/Fleischmanelectroche.pdf](http://lenr-canr.org/acrobat/Fleischmanelectroche.pdf)

Fleischmann M., Pons S., "Calorimetry of The Palladium-D-D<sub>2</sub>O System", Proceedings: EPRI-NSF Workshop on Anomalous Effects in Deuterided Metals (1989), p. 39 of 711 in the PDF file [lenr-canr.org/acrobat/EPRInsfepriwor.pdf](http://lenr-canr.org/acrobat/EPRInsfepriwor.pdf)

Fleischmann, M., *et al.*, "Calorimetry of the palladium-deuterium-heavy water system", (1990), [lenr-canr.org/acrobat/Fleischmancalorimetr.pdf](http://lenr-canr.org/acrobat/Fleischmancalorimetr.pdf)

Fleischmann, M. and S. Pons, "Calorimetry of the Pd-D<sub>2</sub>O System: from Simplicity via Complications to Simplicity", (1992), [lenr-canr.org/acrobat/Fleischmancalorimetra.pdf](http://lenr-canr.org/acrobat/Fleischmancalorimetra.pdf)

Fleischmann M., Pons S. *et al.*, “Calorimetry of the Pd-D<sub>2</sub>O System: The Search for Simplicity and Accuracy”, Proc. ICCF4 1, (1993), p. 23 [lenr-canr.org/acrobat/EPRProceeding.pdf](http://lenr-canr.org/acrobat/EPRProceeding.pdf)

Fleischmann M., Pons S., “Heat After Death”, Proc. ICCF4 2, (1993), p. 106  
[lenr-canr.org/acrobat/EPRProceedinga.pdf](http://lenr-canr.org/acrobat/EPRProceedinga.pdf)

Fleischmann, M. and S. Pons, “Reply to the critique by Morrison entitled 'Comments on claims of excess enthalpy by Fleischmann and Pons using simple cells made to boil’”, (1993),  
[lenr-canr.org/acrobat/Fleischmanreplytothe.pdf](http://lenr-canr.org/acrobat/Fleischmanreplytothe.pdf)

Fleischmann, M., S. Pons, and G. Preparata, “Possible theories of cold fusion”, (1994),  
[lenr-canr.org/acrobat/Fleischmanpossibleth.pdf](http://lenr-canr.org/acrobat/Fleischmanpossibleth.pdf)

Fleischmann, M., “Cold Fusion; Past, Present & Future”, (1998),  
[lenr-canr.org/acrobat/Fleischmancoldfusion.pdf](http://lenr-canr.org/acrobat/Fleischmancoldfusion.pdf)

Fleischmann, M., “Reflections on the Sociology of Science and Social Responsibility in Science, in Relationship to Cold Fusion”, (2000), [lenr-canr.org/acrobat/Fleischmanreflection.pdf](http://lenr-canr.org/acrobat/Fleischmanreflection.pdf)

Fleischmann, M., “Searching for the consequences of many-body effects in condensed phase systems”, Proc. ICCF9 (2002), [lenr-canr.org/acrobat/Fleischmansearchingf.pdf](http://lenr-canr.org/acrobat/Fleischmansearchingf.pdf)

Fleischmann, M., “Background to Cold Fusion: the Genesis of a Concept”, Proc. ICCF10 (2003),  
[lenr-canr.org/acrobat/Fleischmanbackground.pdf](http://lenr-canr.org/acrobat/Fleischmanbackground.pdf)

Fleischmann, M. and M. Miles, “The ‘Instrument Function’ of Isoperibolic Calorimeters; Excess Enthalpy Generation due to the Parasitic Reduction of Oxygen”, (2003),  
[lenr-canr.org/acrobat/Fleischmantheinstrum.pdf](http://lenr-canr.org/acrobat/Fleischmantheinstrum.pdf)

## **Appendix B. Selected Papers on Tritium Production**

N. J. C. Packham *et al.*, “Production of Tritium from D<sub>2</sub>O Electrolysis at a Palladium Cathode”, J. Electroanalytical Chemistry, vol. 270, pp. 451-458 (1989).

R.R. Adzic *et al.*, “Investigation of Phenomena Related to D<sub>2</sub>O Electrolysis at a Palladium Cathode”, Case Western Reserve University Report No. 80 930 October 1990. Available at [www.dtic.mil/dtic/tr/fulltext/u2/a236409.pdf](http://www.dtic.mil/dtic/tr/fulltext/u2/a236409.pdf)

P. K. Iyengar, *et al.*, “Bhabha Atomic Research Center Studies in Cold Fusion”, Fusion Technology, vol. 18, pp. 32-94 (1991) . Also, P. K. Iyengar and M. Srinivasan, “Overview of BARC Studies in Cold Fusion”, Proc. of the First Annual Conference on Cold Fusion, pp. 62-81, National Cold Fusion Institute (1991)

C.-C. Chien *et al.*, “On an Electrode Producing Massive Quantities of Tritium and Helium“, J. Electroanalytical Chemistry, vol. 338, pp. 189-212 (1992).

F. G. Will, K. Cedzynska, and D.C. Linton, “Reproducible tritium generation in electrochemical cells employing palladium cathodes with high deuterium loading”, J. Electroanalytical Chemistry vol. **360**: pp. 161-176 (1993).

D. G. Tuggle, T.N. Claytor, and S.F. Taylor, “Tritium Evolution from Various Morphologies of Palladium”, in Fourth International Conference on Cold Fusion. 1993. Lahaina, Maui: Electric Power Research Institute 3412 Hillview Ave., Palo Alto, CA 94304 and Transactions of Fusion Technology, vol. 26, pp 221-231 (1994) and Los Alamos National Laboratory Report LA-UR 94-971 (1994)

### **Appendix C. Selected Papers on Helium Production**

Y. Arata and Y.-C. Zhang, “Deuterium Nuclear Reaction Processes within Solid”, Proc. Japanese Academy, vol. 72 Ser. B, pp. 179-184 (1996)

D. Gozzi *et al.*, “X-Ray, heat Excess and  $^4\text{He}$  in the D/Pd System”, J. of Electroanalytical Chemistry, vol. 452, pp. 253-271 (1998)

M. H. Miles, “ Correlation of Excess Enthalpy and Helium-4 Production: A Review”, in Proc of the 10<sup>th</sup> Intl. Conference on Condensed Matter Nuclear Science, P. L. Hagelstein and S. R. Chubb (Editors), pp. 123-131, World Scientific (2006)

E. Storms, “How Basic Behavior of LENR Can Guide A Search for an Explanation”, J. Condensed Matter Nuclear Science, vol. 20, pp. 1-39 (2016)

### **Appendix D. Papers from the U.S. Navy SPAWAR-Pacific Laboratory**

Information on, and links to 48 refereed LENR papers from this laboratory since 1991 are at: [https://www.academia.edu/17964553/Condensed\\_Matter\\_Nuclear\\_Science\\_October\\_2015](https://www.academia.edu/17964553/Condensed_Matter_Nuclear_Science_October_2015)

## About the Author

David J. Nagel has been active as a scientist, engineer, manager and teacher of LENR since 1989. He participated in all 20 of the International Conferences on Cold Fusion, and chaired the 14<sup>th</sup> such conference in 2008 on Capitol Hill in Washington DC. Nagel has written numerous technical articles and overviews of LENR, and has presented over 80 talks on LENR in six countries on three continents to more than 4000 people. He is writing a book on LENR.

In 2011, Nagel founded NUCAT Energy LLC, which provides consulting services and instruction on LENR. In 2015, he and Steven Katinsky, an entrepreneur from Los Angeles, formed a not-for-profit company, LENRIA Corporation, to serve as an Industrial Association for LENR. It now advocates for research funding for LENR.

Nagel received a B.S. degree in Engineering Science (Magna Cum Laude) from the University of Notre Dame (1960), and an M.S. degree in Physics (1969) and a Ph.D. in Materials Engineering (1977), both from the University of Maryland at College Park.

He served four years of active duty and 26 years in the U. S. Naval Reserve, including three tours as a Commanding Officer. After his active duty, Nagel joined the civilian staff of the Naval Research Laboratory as an experimental physicist with responsibility for measuring x-ray emissions from nuclear weapons, other multi-million degree plasmas and energetic atomic collisions. He co-invented plasma x-ray lithography. Nagel served as a head of a materials physics group at the Naval Research Laboratory for 13 years. Then, he became a member of the Senior Executive Service, and the leader of a solid-state and nuclear physics division, again for 13 years. There he managed experimental and theoretical research and development efforts of 150 government and contractor personnel, including 80 PhDs.

For the last 18 years, Nagel has been a Research Professor in the Department of Electrical and Computer Engineering of The George Washington University. He taught graduate level courses on MEMS, NanoTechnology and Physical Electronics for several years. Now, Nagel mentors both undergraduate and graduate students. His current experimental research centers on Low Energy (or Lattice Enabled) Nuclear Reactions using electrochemical interactions of protons with nickel and co-deposition of deuterons and palladium, both approaches monitored with various thermal and spectroscopic techniques.

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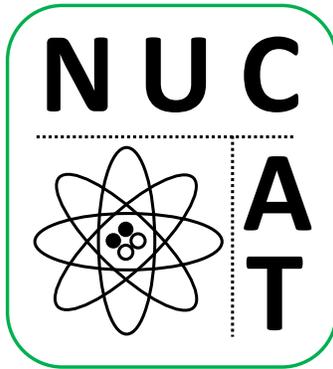
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