The Basic Nature of the Cold Fusion Effect

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ABSTRACT

Cold fusion or low-energy-nuclear-reaction (LENR) is one of the great discoveries of this century. Unfortunately, it is largely rejected and ignored by conventional science. This paper provides a brief description of the author's involvement in the experimental study of the effect along with how he believes the process functions. Important literature is cited and used to show why the effect is not the result of poor science as is commonly believed.

Keywords

Cold fusion, LENR, transmutation, nuclear process, ideal energy,

INTRODUCTION

Twenty-nine years have passed since Profs. Martin Fleischmann and Stanley Pons (F-P)[1-10] promised the world a source of clean, cheap, and unlimited energy, first called cold fusion and now low energy nuclear reaction (LENR). They claimed energy could be produced by causing nuclear fusion between deuterons present in a rare kind of palladium during electrolysis. To most people, this sounded like a normal claim common in science these days. Few people realize how much pain and suffering F-P experienced by trying to bring this gift to mankind. This idea was welcomed at first with enthusiasm and then rejected with great intensity,[11-36] encouraging Prof. Pons to move his family to France and give up his US citizenship to avoid the harassment. The two professors later expanded their work in France where they continued to report success.[37]

Many details about LENR are not available because many conventional scientific journals would not accept papers about this subject. Nevertheless, much information can be found at www.LENR.org and in the Journal of Condensed Matter Nuclear Science (http://www.iscmns.org/CMNS/CMNS.htm). A good history of the early days can be found in the book "Fire From Ice" by Mallove.[38] Later events are described by Beaudette in "Excess Heat: Why Cold Fusion Research Prevailed"[39] and by Simon in "Undead Science: Science Studies and the Afterlife of Cold Fusion" [40]. Other books are available having a negative slant with the most biased being "Cold fusion: The Scientific Fiasco of the Century" by Prof. Huizenga[41]. He was the co-chairman of and had a major influence on the conclusions of the ERAB panel[42] that were used by the DOE to justify official rejection of the claim. As you can see, he made no attempt to hide his bias. Other books with a negative bias are also available.[41, 43-45] The conclusions in these books are interesting to compare to what is now known to be true. If being accused of doing poor science can result in loss of reputation and possible employment, what loss comes from being wrong about such an evaluation?

The reader might be tempted to ask, "Why would a scientific discovery cause so much controversy"? After all, this source of energy might improve the ability of civilization to survive in the time of global warming and allow human travel to other planets. The stakes could not be greater.

What is a rational person to believe? We are presented with behavior that appears to be in direct conflict with what we know and accept about nuclear reactions. At the same time, we are given an apparent gift by Nature of great potential benefit. Is this conflict worth resolving or not? Having seen the LENR reaction take place many times in my laboratory, I found this question easy to answer.

MY INVOLVEMENT

Experimental studies

My interest started shortly after F-P announced their discovery on March 31, 1989, while I was working at Los Alamos National Laboratory (LANL) on programs exploring the use of nuclear energy in space. Scientists at LANL were very interested because, if true, the discovery could the supply energy needed for space exploration, a problem still largely unsolved. Because scientists are not given this kind of challenge very often, the laboratory became galvanized by a kind of excitement not experienced since the war years. Dozens of studies were undertaken throughout the laboratory. While success in replicating the claim was rare, it was real. Since then, similar studies have been made in laboratories located in at least 12 countries with the results reported in over 2000 peer-reviewed papers.

With brief support provided by the Department of Energy (DOE), Carol Talcott, my future wife, and I set about making tritium using the F-P method. After successful production of tritium in an ordinary electrolytic cell, the results were published after extensive review by scientists at the laboratory and later by reviewers chosen by the journal.[46] As you can imagine, this was not an ordinary paper without controversy. Following this success, I wrote a review[47] that summarized all published information available to me at the time. By then the DOE had terminated all official funding. This review was used to justify internal funding to construct a calorimeter and to study samples of palladium provided by Prof. A. Takahashi (Japan)[48], who had a batch of palladium he found could make excess energy. Our study also demonstrated production of excess energy from two of the three samples he provided and the result was published after extensive peer review.[49] This work was one of the first examples of independent laboratories seeing the same effect when the same material was studied.

Although the excess energy could not be proven to result from a nuclear reaction, the chemical and physical conditions within the electrolytic cell as well as the large amount of energy allowed for no other possibility when correctly evaluated, in spite of efforts by many people to find prosaic explanations. Of course, production of tritium, and the later detection of helium do not suffer from the same kind of ambiguity. These nuclear products added further support for the source of energy being an unusual nuclear process, as described later in this paper.

Another way to evaluate whether the behavior results from LENR rather than from a prosaic process is to determine whether the behavior is influenced by variables that have no relationship to the proposed prosaic process. I explore two such variables; these being the effect of temperature and the effect of what I call production of excess volume, as described next. Neither of these variables would be expected to affect a prosaic process, such as an error in measuring power using a calorimeter.

Production of excess volume is produced as result of the physical expansion when palladium reacts with hydrogen or deuterium. Strangely, this expansion is not eliminated when the hydrogen is removed. As result, if a piece of palladium were subjected to repeated loading-deloading cycles, it would gradually turn into a cube with greater volume than the original sample, regardless of its original shape. This process was later explored in detail [50, 51]. Each batch of palladium has a different susceptibility to this process, with batches having less susceptibility being more likely to support the LENR process. In other words, a condition is present in each batch of palladium as result of its purity and treatment that can affect creation of excess volume in addition to the LENR process. This behavior demonstrated just how critical the nature of the metal is in causing initiation of the LENR effect. Apparently, a rare and relatively local condition[52, 53] is necessary and can be created throughout a batch of palladium, such that most pieces of palladium taken from the same batch show similar behavior. This characteristic has been found to apply to palladium when in the form of both wire and sheet.

While I doubt application of a little external energy could affect the nuclear process itself, a modest increase in temperature is observed to cause an increase in the overall rate of power production, as shown in Fig. 1. I suggest this increase in power

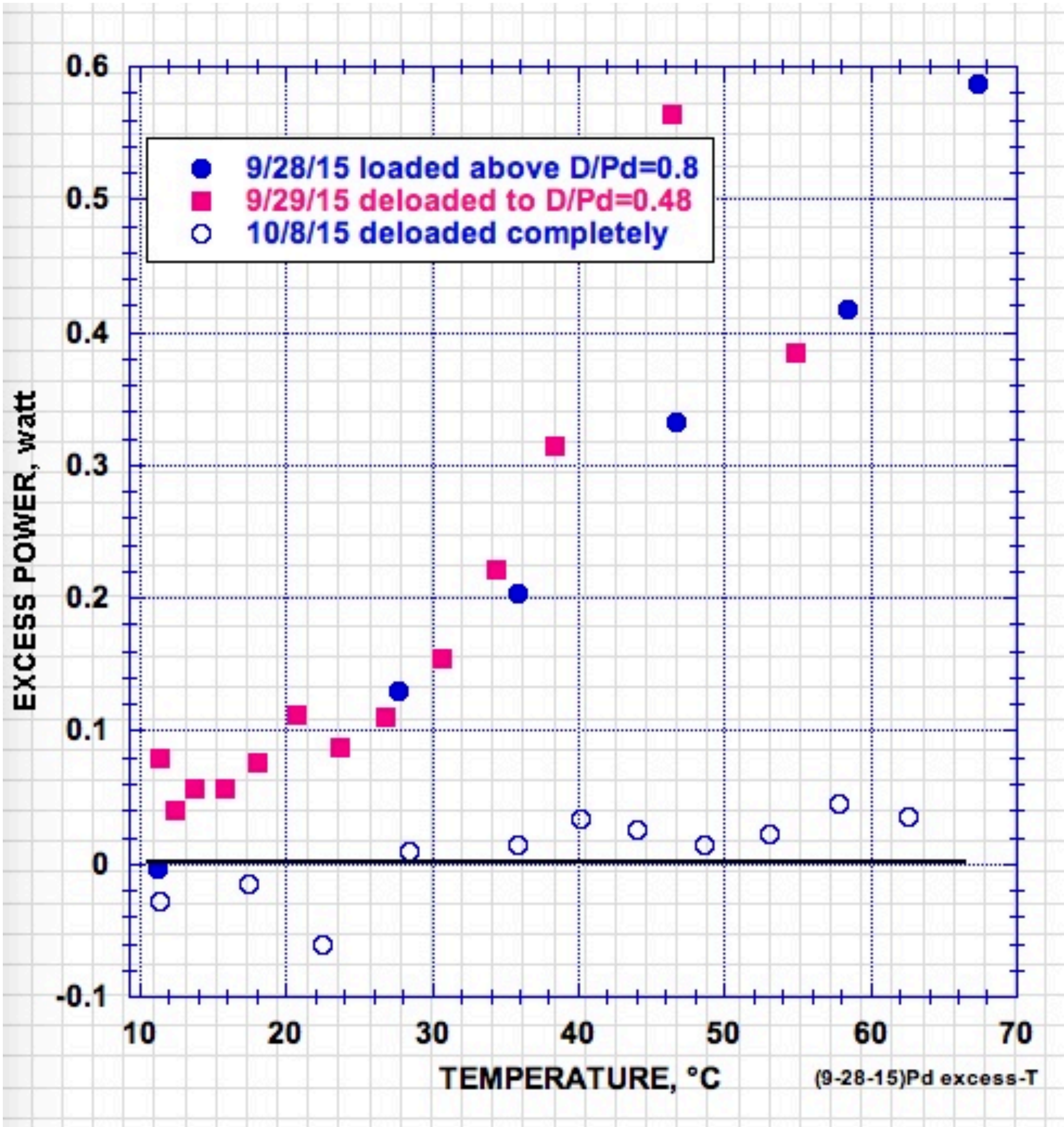

FIGURE 1. Effect of temperature on power production for various samples of PdD containing different D/Pd ratios. Complete loss of D results in no power production.

results from the increased rate at which deuterium can diffuse to the NAE in order to replace deuterons being destroyed by the fusion reaction. This conclusion is justified by the effect of temperature on the amount of power being produced being similar to the effect of temperature on the rate of diffusion of D in PdD.[50, 54]

In spite of this repeated success at LANL and many other positive results reported by numerous other laboratories, the DOE[42] terminated studies of cold fusion at LANL and at other government laboratories in 1989, less than a year after the discovery was revealed. With this betrayal of scientific integrity in mind, I retired. Or more exactly, I changed jobs.

My wife and I set about designing and constructing with our own hands a home in Santa Fe with an attached laboratory and a breath-taking view of the entire Rio Grande Valley. My work continued there and resulted in over 100 publications, 16 reviews[47, 55-69], two books[70, 71], and a growing library of over 5400 publications by various authors describing the full range of the phenomena. This extensive library, based on the Endnote system, was used to create the publically available library (LENR.org) administered by Jed Rothwell. In the process, I saw many artifacts, explored many errors, while finding much evidence to support the claim. Being the designer, manufacturer, and user of the equipment allowed great control over all aspects of the study.

With this description in mind, what evidence supports LENR as being a real phenomenon? Let's start by examining the difference between cold and hot fusion?

THE NATURE OF FUSION

Hot Fusion

The hot fusion process has been studied for the last 80 years using very hot plasma to initiate the nuclear process between isotopes of hydrogen.[72] This reaction is now being used in an attempt to make commercial energy by fusing deuterium (d) with tritium (t) according to:

$$d + t = n(14.1 \text{ MeV}) + {}^{4}\text{He}(3.5 \text{ MeV}).$$

Because the reactants must be heated in excess of 100 million degrees, large machines of complex design[72] are required. Although the amount of energy produced can be large, it is not yet large enough to both run the huge machine and produce useful energy[73, 74]. Use of tritium in the fusion reaction creates added difficulty because expensive nuclear reactors must be used create enough of this unstable isotope to offset the inefficiency involved with creating tritium from the emitted neutrons (n). In other words, this method is still far from being a source of practical commercial power.[74]

Similar behavior is observed when a material containing deuterium is bombarded by energetic deuterium ions [75-82]. Even though the reaction takes place in a solid material, the reaction products consist of energetic neutron, tritium, proton and helium-3 in equal quantities. These products are typical of and consistent with the hot fusion mechanism that results when high-applied energy is used to cause fusion by brute force. The fusion rate can be slightly modified by the material but not the nuclear products.

Much attention has been directed toward causing fusion by using muons in place of electrons in the D_2 molecule.[83, 84] This substitution causes the two nuclei to get close enough to fuse without high energy being required, suggesting muons might be involved in cold fusion process.[85, 86] Unfortunately for this idea, the products resulting from the hot fusion mechanism are produced. Consequently, even though high energy is not required, the resulting mechanism is not like the one that causes cold fusion. In other words, simply forcing the nuclei close enough for the strong force to take over does correctly explain the process. The cold fusion process is obviously more complicated than simply overcoming the Coulomb barrier.

Cold Fusion

To summarize, the cold fusion process (LENR) is very unusual because it occurs only in solid materials without the need to apply significant energy. Large and complex machines are not needed and dangerous radiation is not produced. Further advantage results from the fuel being only deuterium found in ordinary water. As result, this method has the potential to be the ideal source of energy after the process is better understood. What do we know so far?

When deuterium is fused, the main nuclear product appears to be ordinary helium (^4He) along with production of what are called transmutation products.[87] These new elements result from nuclear reactions between deuterons or protons with various other elements in the material. In addition, these reactions have been observed to even affect the radioactive decay rate of elements present in the material, such as result from environmental contamination produced by failed fusion reactors.[88, 89] This effect is now being explored as a way to clean up such contamination.

Before going into detail, several important general behaviors need to be acknowledged first. The abnormal energy is observed at isolated locations in a variety of materials. Once started, energy production is stable for many hours and frequently reproducible when the sample is again studied provided all the hydrogen has not been removed. The effect has been initiated several different ways, all of which make hydrogen ions available to the NAE as result of diffusion within a solid to where the NAE is located.

But energy alone is not proof of a nuclear process. This conclusion requires the detection of the nuclear products. The proof gets stronger when the amount of nuclear product is found to be consistent with the amount of energy expected to result from a known nuclear reaction. Figure 2 compares sixteen values from four independent studies of helium detected in the

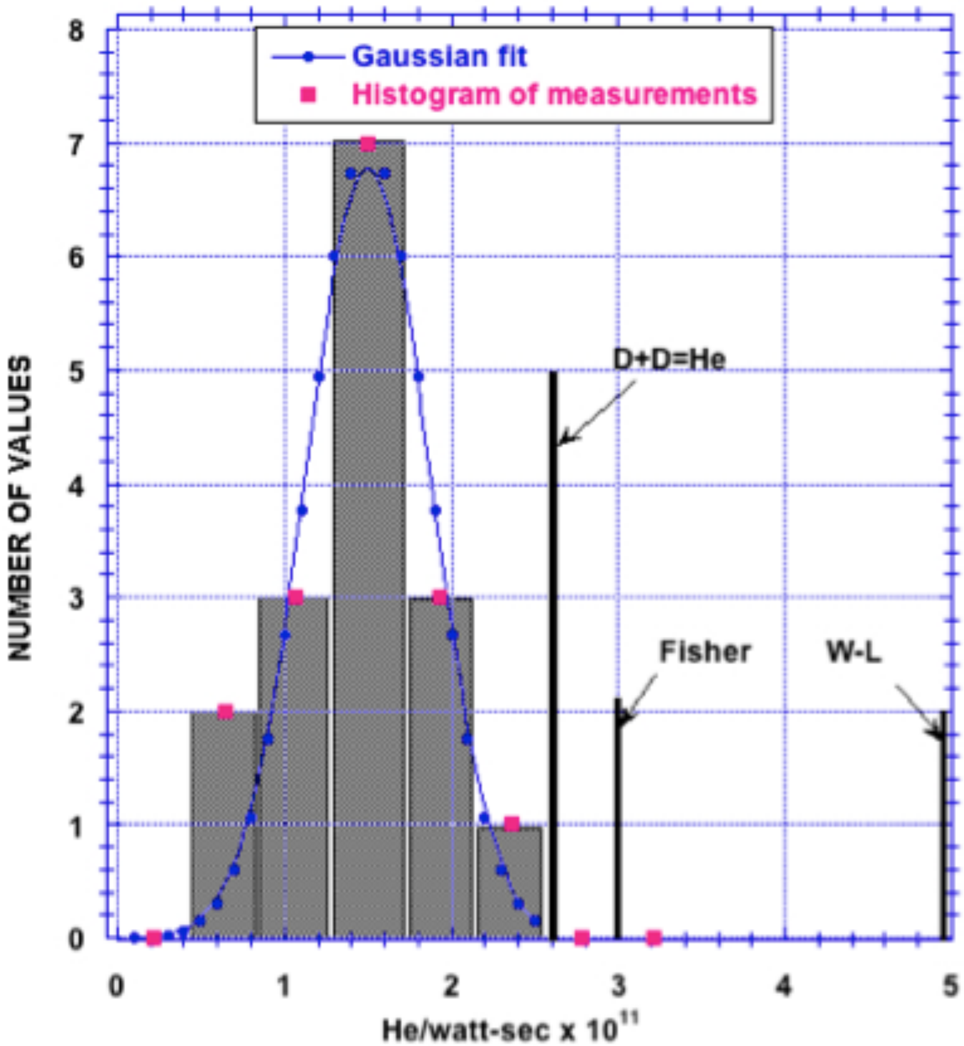

FIGURE 2. Histogram of all the measurements from which the ratio of helium/energy can be calculated. The measured values are compared to those resulting from the mass change when helium forms from deuterium and to several theoretical predictions. The Gaussian fit indicates the range of values results from random error. The helium value is obtained from that which leaves the sample and does not include the He that remains in the Pd.

surrounding gas generated by electrolysis along with the energy being made. The resulting ratio of He/energy is important because it results from the interaction between two separate and independent measurements. Consequently, the ratio has more importance than would values based on energy or amount of helium alone. The ratio is important because it can be compared to the energy produced by the change in mass resulting when two deuterons are converted to helium. This reaction creates 23.8 MeV/helium or $1.6x10^{-11}$ He/watt-sec, which is shown as the vertical line on the figure. The measured values for this ratio are assigned to bins with the number of values falling within each bin being plotted. The symmetrical relationship and the excellent fit to the Gaussian Error Equation is consistent with random errors being the cause of the data scatter, in contrast to systematic errors being present. The center of the measured values is about 50% less than the expected value because some helium is retained by the PdD cathiode, which was not measured.

Because energy and helium involve independent measurements with separate errors, the probability is essentially zero for this close agreement within the data set and with the expected amount based on the mass change to result from random chance or a combination of systematic errors. If such errors were present, the ratio would be expected to fall at random values from near zero to infinity instead of being tightly clustered. However, the measurements are not precise enough to identify other possible nuclear reactions taking place at the same time as D-D fusion, such as fusion of normal hydrogen or transmutation. Nevertheless, D-D fusion is apparently the major source of helium and energy. As can be concluded from the figure, the observed behavior is in basic agreement with the model proposed by Fisher[90] but differs by a significant amount from the predicted values given by Widom and Larsen (W-L). [91]

The exact amount of helium retained by the palladium is a variable worth exploring in the future in order to better understand the location from which it originates, which is near the surface of the palladium cathode. Although some retention is expected, the depth from which helium diffuses determines the amount retained, with a deeper source retaining more helium. The present retention is consistent with an average production depth of about 10 microns when electrolysis is used with LiOD in the electrolyte.

Why the nuclear reaction favors the surface region is important to understand. Three variables may play a role. [1]Because the surface might achieve a large D/Pd ratio, a new structure might form in which the NAE is present. [2]The stress produced by reaction with D is concentrated near the surface where crack formation might favor formation of the NAE. [3]Lithium accumulates in the active surface region as result of electrolysis where it replaces palladium in the fcc structure, perhaps by causing NAE formation as result of a change in the amount of stress in the surface region or by being one of the nuclear reactants. [92-94]

Helium production is not the only nuclear product. Tritium is also detected on rare occasions, which also originates from sites near the surface.[51] That both nuclear products are produced in the same small region of the material is an important observation with a relationship to the reality of the nuclear process and how it must function. Further support is provided as the various errors and prosaic explanations offered by skeptics have all been explored and found not to apply. In addition, a third nuclear product, consisting of a few neutrons, is produced along with tritium, but not at a rate consistent with the source being hot fusion. As shown in Fig. 3, the measured tritium/neutron ratio has large spread in values that might result from error but the values might also

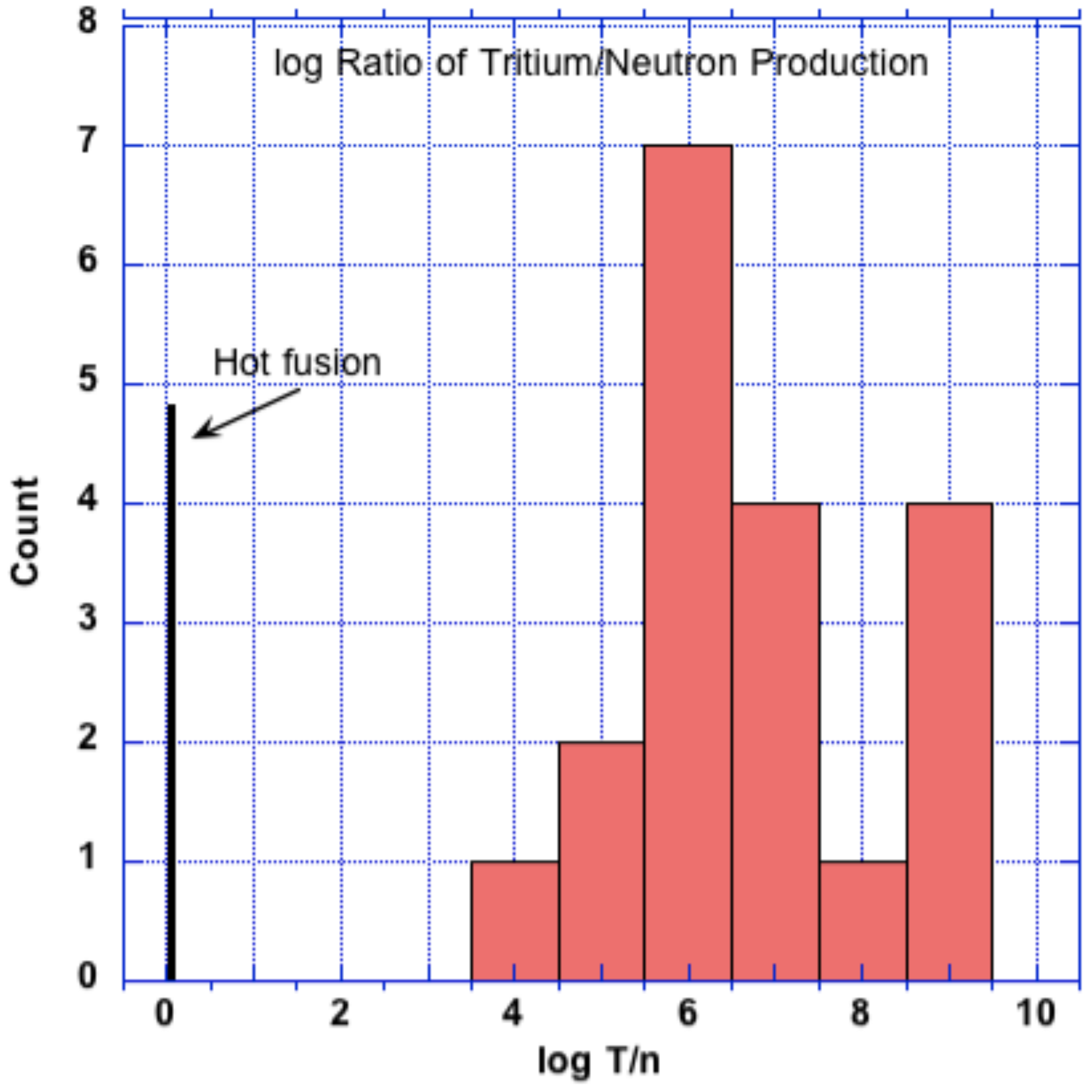

FIGURE 3. Histogram of samples for which the tritium/neutron ratio is measured. The value produced by the hot fusion process is shown.

result from variations in the respective rates for independent production of tritium and neutrons. In other words, these two products might result from related but largely independent mechanisms. Various researchers have suggested the tritium results from fusion between a deuteron and the proton impurity during which an electron is added to the nuclear product.[70, 95-97] Once tritium forms, it might fuse with a deuteron and an electron to produce a neutron, an electron, and He^4. This reaction would result in a weak relationship between the tritium concentration and the production rate of neutrons, as the figure suggests. These ideas are worth exploring even though tritium production is always to small to cause detectable heat energy.

Radiation is another expected result of a nuclear process. In all cases, the radiation detected outside the apparatus has a very small flux and low energy, much less and at much lower energy than would be expected from the amount of energy being produced based on the amount of heat being measured. This behavior is proposed to result from the energy being emitted over a period of time in smaller quanta rather than all at once as one big quantum, as is characteristic of the hot fusion process. These smaller quanta have too little energy to leave the apparatus. Instead, most are converted to heat by the conventional process within the apparatus. In other words, LENR could be called slow fusion while the conventional hot fusion could be described as fast fusion. While a fast nuclear process would be expected when high energy is applied, a different kind of energy emission process might become possible when the Coulomb barrier is reduced in a lattice structure without the need to apply high energy. As result, the process has many characteristics of radioactive decay from an unstable nuclear energy state created under rare conditions within a chemical structure.

With this general background in mind, let's look at the scientific problem in more detail. Although the electrolytic method, as pioneered by Fleischmann and Pons, is used most often, it is not the only one found to cause LENR. Nor is palladium the only material able to support the process. Nickel metal [98, 99], as well as titanium[100] and some complex compounds [101-103], have been found work as well. High voltage can be applied to D_2 gas during which the resulting D+ ions are caused to react with palladium metal. The result is similar to the electrolytic process as far as the conditions in the palladium are concerned but with the source of hydrogen ions being different and higher local temperature being produced. In this case, the nuclear products typical of the cold fusion reaction are produced rather than those known to result from the hot fusion process as long as the energy of the bombarding ions remains too small to cause hot fusion.[80]. Even simply heating some materials in D_2 gas has been found to produce the cold fusion reaction products. Dr. L. Case[104] produced excess energy and helium using Pd deposited on charcoal, as is typical of a chemical catalyst. This claim was replicated by McKubre.[105] Mixtures such as ZrO_2+Ni[106] and ZrO_2+Pd[107] produced energy when heated in D_2. Complex materials such as $SrCeO_3$[102] and $LaAlO_3$[108], each containing deuterium, have been caused to produce anomalous energy when current is passed through the material. Clearly, the unique condition required to support LENR can be created in a variety of materials when exposed to a variety of treatments. This apparent ability of LENR to occur in several kinds of materials adds further support to its reality and helps theoreticians focus on how an explanation has to be formulated.

The transmutation process adds even more complexity. Apparently, heavy nuclei present as impurities or even the palladium itself can acquire extra mass as a result of the LENR process and sometimes split into smaller nuclei, thereby releasing energy.[109-164] Work by Dr. Iwamura et al.[165-183] at Mitsubishi Heavy Industries, Ltd. (Japan) demonstrated simultaneous addition of as many as three helium nuclei to various elements deposited on alternating layers of Pd and CaO when deuterium is passed through the sandwich. This special material was found to generate energy during the process. Prof. Miley et al.[127, 128], using plastic beads coated with Pd, made a very careful study of various transmutation products accumulated while energy was produced and measured. He found a complex collection of elements that could be explained by the addition of deuterons to the palladium nucleus followed by fragmentation. Other researchers have reported similar behavior.[147, 184, 185] Although the rates of these reactions are small, the accumulated nuclear products are easy to detect but very difficult to explain. Leading the list of difficult questions is, "How can the very large Coulomb barrier be overcome"? I made an attempt to suggest an answer in my book [71] based on the assumption that fusion is required to cause transmutation. In other words, the NAE is proposed to support the fusion process, which at the same time supplies the energy required to overcome the large Coulomb barrier for transmutation. Clearly, the nuclear process is complex and very unusual, with very little relationship to the kinds of nuclear interaction known to involve the strong force.

MODEL OF THE LENR PROCESS

In addition to my experimental studies, I tried to construct a model of the behavior to be used as a guide. This effort joined a growing collection of models being proposed by other people. In my case, the emphasis is on identifying where in the material the nuclear process occurs, which I call the nuclear-active-environment (NAE). The goal is to find ways to make the NAE with reliability and in large quantity. Because such an unusual and rare process would be expected to occur in only a single kind of unique structure, this feature would need to form in the many different kinds of materials known to produce LENR. I concluded that gaps of a critical dimension satisfy the requirements, which could be created as result of stress relief during the reaction with hydrogen.[71, 186-188] Grain boundaries and inert inclusions are the most likely sites where stress relief would cause the material to separate. Furthermore, the gap dimension is very critical, with large gaps being unable to support the LENR process. Unfortunately, Nature tries to turn small gaps into large gaps, thereby working against formation of the NAE. In view of this behavior, how could the proposed NAE be formed on purpose?

My model describes the LENR process to consist of three separate phases. Each phase needs to be understood separately, with the first phase being formation of the NAE. I propose the NAE consists of a gap structure created as result of stress produced when the material reacts with or loses hydrogen. This process would be sensitive to the rate of change of the H/Pd ratio and the final value, with values above about $PdH_{0.85}$ being required to start gap formation.[189] During the second phase, the gaps are filled with D and/or H, which I propose form a stable chemical structure as result of Gibbs energy release. I call this chemical structure a Hydroton and propose it has properties similar to metallic hydrogen.[190-193] Many Hydrotons containing different numbers of H or D atoms are proposed to form where the gap happens to have the required dimension. Once formed, these structures maintain the gap at the critical dimension as they fuse and then reform. In other words, this formation reaction follows all the rules governing chemical processes and, up to this stage, the process can be described as a totally conventional chemical process. The final phase involves a nuclear process that takes place without additional intervention. I have described this part of the process elsewhere [71, 186, 187, 194, 195] but without the mathematical detail many people like to see. This omission is done on purpose because an emphasis on the nuclear process is not useful at this time. Such information does not advance the ability to cause LENR. Once LENR can be caused at will, the required details about the nuclear process will be easy to obtain. I predict this information will eventually lead to an entirely new field of study the discovery by F-P made possible.

CONCLUSION

No doubt, the experiment studies contain error just like all measurements. Nevertheless, the many similar results and patterns of behavior eliminate error as the cause of the basic behavior. The issue boils down to a simple choice. Either the observations are real and reveal a new kind of nuclear process or many hundreds of scientists in laboratories all over the world have been making errors for the last 30 years that have been ignored in hundreds of peer reviewed papers.

The nuclear process is clearly unique and has not been previously identified in nature, although tritium production[196] in the earth's magma suggests such a reaction might occur in the natural environment. That such a novel nuclear process could occur is the important discovery made by F-P, although they did not know it at the time. Amazingly, their work revealed a new kind of nuclear interaction made possible by the nature of a chemical structure. This conclusion has been difficult for conventional science to accept because chemical conditions are not found to interact with nuclear processes, except on very rare occasions (https://en.wikipedia.org/wiki/Electron_capture).

Ironically, the long-term future of civilization appears to depend on either an energy source too complex to be practical (hot fusion) and on a source too strange to be believed (cold fusion). Nevertheless, a rational person might ask why are money and skill focused mainly on an apparently impractical and very expensive method while another approach remains largely unexplored? Why put all the eggs in one basket? Isn't science supposed to solve difficult problems and in the process find beneficial solutions?

The debate about the reality of LENR has now been resolved. LENR is real. Now we need to discover how it works. The race is on.

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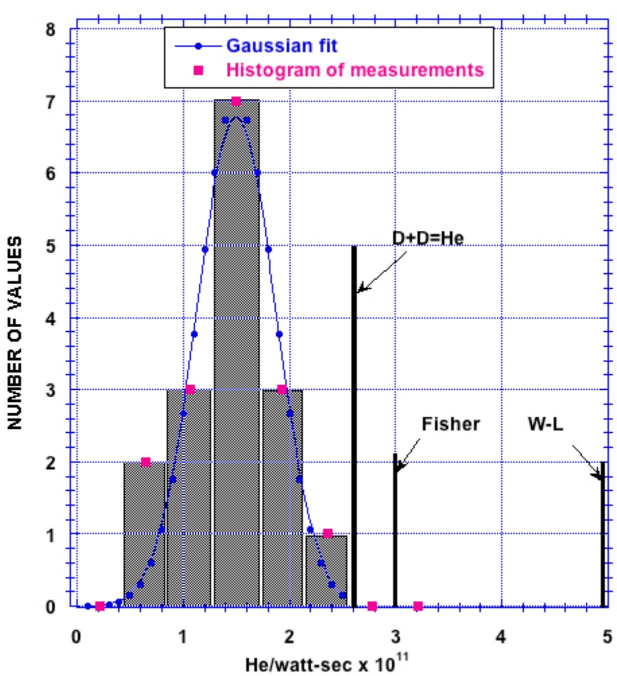

FIGURE 1. Histogram of the measured (He/energy) ratio compared to that calculated from the mass change for the D+D=He reaction and from several proposed mechanisms. (Storms [89])

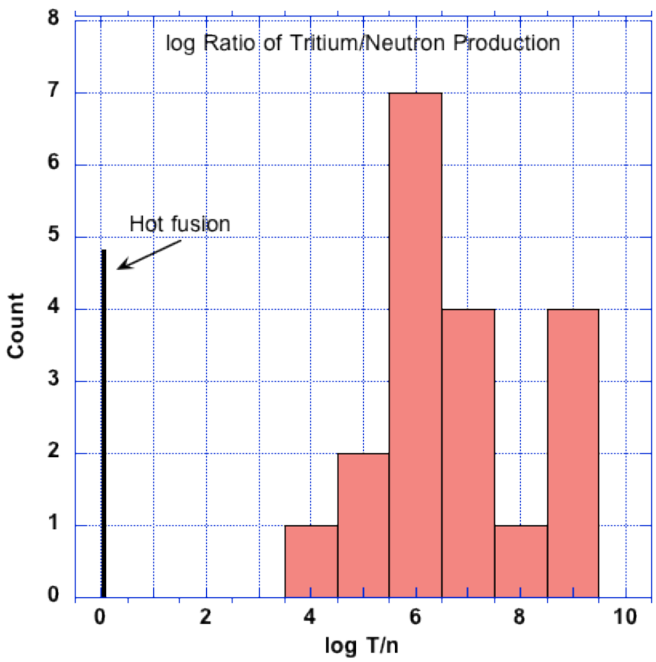

FIGURE 2. Histogram of log (tritium/neutron) ratio compared to the ratio produced by the hot fusion mechanism. (From Storms [89])

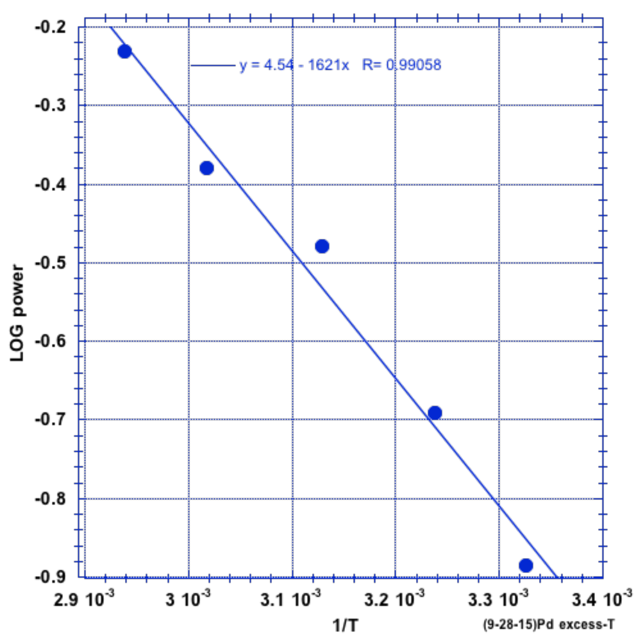

FIGURE 3. Log power production vs 1/T for the LENR process involving deuterium using the electrolytic method. [189]