A New Understanding of Cold Fusion

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Abstract: A brief description of selected information presently known about the fusion process called cold fusion is provided and used to support a general description of how the process is proposed to work. The new information also includes the results from new studies involving electron emission and the effect of applied electron current.

The nuclear process results from an unusual chemical condition in which a structure forms involving many electrons and a few hydrogen nuclei that cause nuclear fusion of the contained hydrogen isotopes. This fusion process has two important features. It may be a source of clean, inexhaustible, and inexpensive energy. In addition, it has revealed a new kind of nuclear process. Although this proposed mechanism could not yet be described in mathematical detail, its major features can be identified and used to guide future studies.

1.0 INTRODUCTION

Thirty-three years ago, Profs. Martin Fleischmann and Stanley Pons (F-P) (University of Utah) announced a discovery that confounded the scientific community[1]. This discovery involved the ability to cause a fusion reaction between nuclei of deuterium in ordinary palladium metal when it was reacted with D_2O in an electrolyte cell at room temperature. This process is expected to provide a safe, pollution-free, and inexpensive source of energy having a great benefit to society.

Before addressing the unique nature of this discovery, we must first deal with the widely believed myth that the effect is not real and results from faulty measurements.

As conventional understanding demonstrates, such a fusion reaction would be impossible because the energy required to overcome the Coulomb barrier is not present and the nuclei in ordinary material are normally too far apart to interact. Even if such a reaction were to occur, the reaction products produced by the conventional hot-fusion mechanism[2] would be expected. The expected neutrons were sought but not found in the required numbers. Furthermore, most people could not replicate the claimed heat production. These issues combined with political considerations in the USA caused a myth to be created that lives even today. Huizenga[3] gives the scientific reasons for the rejection and Krivit[4] describes how the rejection was accomplished.

Although the nuclear process is a challenge to produce for reasons now understood, the behavior is obvious and unambiguous when it occurs. The absence of significant neutron emission is now known to be characteristic of cold fusion, with the occasional detected neutron emission being caused by a different reaction. Several reaction products related to the fusion reaction and the occasional transmutation reactions have been identified by many independent studies.[5] Heat energy is the main nuclear product, with the amount being much greater than provided by any plausible chemical reaction.

A skeptic might reasonably reject a single measurement or a collection of measurements after a common error has been identified, but a consistent collection of behaviors made by many independent studies, as is the case here, is the kind of fundamental evidence on which all scientific ideas are judged. Various treatments are now known to affect the process in ways that eliminate error or any prosaic process as the reason for the behavior. Indeed, all of the requirements demanded by the skeptics and by general science have been met. The challenge now is to discover how the process works, which is the goal of this paper. The goal includes suggestions as to how the proposed explanation can be tested. An explanation is made more complex because many additional nuclear reactions, besides fusion, have been produced in various materials using a variety of treatments. Because additional nuclear reactions can occur, the original name of cold fusion has been changed to "low energy nuclear reaction" (LENR) or sometimes "condensed matter nuclear science" (CMNS). Nevertheless, this paper focuses only on the claims made by F-P that involve the production of significant energy as the result of fusion when PdD and other similar compounds are exposed to deuterium after being subjected to special treatment. In addition, because this paper is not a review, only a few examples of the reported behavior are cited. Also, the various explanations that conflict with the mechanism described here are not evaluated. Instead, features of a process that must be acknowledged by all explanations are identified and then applied as a proposed unified description.

Before discussing the F-P claims, the reader needs to understand that two different mechanisms can cause fusion to occur in a material. The mechanism discovered by F-P occurs without the application of energy, hence is called cold fusion. In contrast, the other mechanism requires the application of significant extra energy, usually in the form of kinetic energy applied either in plasma or during ion bombardment. Hence the mechanism is called hot fusion. Because these two methods produce different nuclear products at significantly different rates, they cannot involve the same mechanism. Only the cold fusion mechanism is described here.

These conflicts in understanding are explored by asking a series of questions to which answers are obtained from experimental observations, not from theory. Then, studies are proposed to obtain better answers that could lead to an effective design for a practical generator of energy.

Copies of the ICCF conference papers, papers published in JCMNS, and many of the papers cited here can be found at www.LENR-CANR.org.

2.0 OVERALL BEHAVIOR

The process can be viewed as the consequence of four separate stages, with each understood as a separate event. The first two stages involve the rules normally applied to chemical behavior and the last two involve the rules that apply to nuclear processes. These stages are discussed in more detail in Section 4. But first, the general features of each stage are described.

2.1 Chemical issues

The D atoms in a chemical system are normally too widely separated to allow nuclear interaction. This separation is controlled by the electron structure to which the rules governing crystal formation apply. For fusion to occur, the nuclei and electrons

need to acquire an entirely different relationship without violating the rules that apply to all chemical systems. We can say that the initial chemical process involving the assembly of nuclei and electrons does not anticipate a nuclear reaction being the consequence. Next, we need to determine where in the material this assembly can form.

Many of the materials in which cold fusion occurs, such as PdD, consist of a face-centered-cubic (fcc) crystal structure in which the atoms are arranged in a regular array. This array has the lowest energy of any other possible arrangement. Therefore, for the deuterium nuclei to achieve a new condition required for fusion, the process has to function outside of the lattice structure where the chemical environment is not controlled by the rules governing the crystallographic arrangement. This consideration eliminates vacancies in the lattice structure as the site of the fusion process. Otherwise, these sites would no longer be vacancies and the structure would no longer be fcc if these sites were occupied by atoms. In addition, for this new structure to form, the D in the resulting structure must be more chemically stable compared to where it is located within the lattice structure. Otherwise, the D would not leave its position in the normal lattice structure and move to form this new structure, as Gibbs energy is lost. This issue is discussed in greater detail in Section 4.2.3. So, we are confronted by a unique chemical problem right from the start even before we try to understand how fusion might be accomplished.

Because the fusion process requires the formation of unique chemical conditions and because these sites are rarely formed, the total number of such sites and how often fusion can occur at each would determine the amount of power, not the rate of the nuclear reaction itself. Although the fusion reaction would require some time to occur, its rate would be expected to be far faster than the assembly process, both during the initial formation of the required structure and as D is replaced by diffusion after being converted to a different element.

2.2 Nuclear issues

Fusion requires the nuclear energy states of two deuterons to interact such that a new energy state is created as a stable nuclear product. This interaction requires a reduction in the Coulomb barrier so that the nuclei to get close enough for this energy sharing to take place. Two processes can achieve this goal. These are applied energy and electron screening. Because applied energy is normally not available when cold fusion occurs, the explanation must focus on electron screening. This process can also be called tunneling by which the interaction takes place without being limited by the full force of the energy barrier. Although electron screening is found to lower the barrier when ion bombardment is used to trigger the hot fusion mechanism, the amount is trivial compared to the screening required to cause cold fusion.[6] When cold fusion occurs, a much greater magnitude of screening has to operate to produce the observed reaction rates. The challenge is to explain how this greater screening process might work. This problem is discussed in Section 4.2.2.

After fusion has occurred, the resulting nuclear energy must be dissipated while momentum is conserved, which requires the emission of two or more nuclear products. In the case of cold fusion, only one nuclear product has been identified as the source of all the measured energy, which is ^{4}He. This creates a problem because a single nuclear

product cannot dissipate nuclear energy while conserving momentum. A second emitted particle is required. A solution to this problem is suggested in Section 4.2.3.

The nuclear process can take place in many materials, not just in PdD as was initially used. Also, many methods besides electrolysis are now known to initiate the process.[7] Furthermore, both deuterium (D) and ordinary hydrogen (H) will produce similar amounts of nuclear power. These behaviors demonstrate the existence of a universal behavior that is not caused by a particular environment, hydrogen isotope, or treatment.

Finally, the released nuclear energy has to be dissipated, but without producing energetic radiation that is not detected outside of the apparatus. Neutron emission is rare and seems to be produced by secondary reactions. Nevertheless, some radiation and several nuclear products are detected[8, 9] when an effective search is made within the apparatus. This radiation holds the key to understanding the complexity of the process and is discussed in Sections 3.9 and 3.10.

I evaluated a few of the many proposed models in my book.[10] This paper will not repeat this critique. Instead, another explanation is added to the growing list. In this case, the model is based only on the observed behavior and a few justifiable assumptions, without any effort being made to apply mathematics or quantum mechanics. Instead, the patterns of behavior are identified and a logical relationship between them is suggested. This approach is used to reveal how the nuclear process could be amplified and provides many ways to test the model by using predicted behaviors. A path is suggested to understand the process in greater detail so that future studies can be done using a more effective design.

In summary, cold fusion appears to involve a series of chemical processes that accidentally result in a nuclear reaction when isotopes of hydrogen are present. When the suggested explanation is evaluated, it's worth considering that these unique chemical conditions may be common but have been overlooked in the past because they did not result in an observed nuclear event and hence would be identified as normal chemical behavior. Rather than rejecting the ideas out of hand because they are not consistent with expectations, I suggest the predictions be tested to determine what is real and what is only imaginary, as is normally required in conventional science.

Finding a path to understanding and applying this phenomenon is important because it has the potential to provide the ideal source of clean energy that is required for civilization to survive in the future.

3.0 DISCUSSION

Two questions are answered here before an explanation is proposed. These are: (1)which behaviors are important as support for an explanation, and (2)which assumptions are necessary and how are they justified? Only the important behaviors are described along with their significance to an explanation. As you will see, each of these behaviors fits together like the pieces of a jigsaw puzzle to create a picture of the process, although one that is still incomplete. When viewed in combination, the selected behaviors provide overwhelming evidence for the reality of LENR and reveal which pieces of the puzzle are missing. The important pieces involve energy production, the production of nuclear products, and the emission of energetic radiation, all with a logical

relationship to each other, as described below. This combination of behaviors demonstrates that a nuclear reaction is the source of the observed energy.

3.1 Energy Production

Energy production greater than any plausible chemical source is the frequently observed characteristic of cold fusion. The energy is measured as power expressed as watts using calorimeters of various designs. The initial rejection was based on there being errors in such heat measurements. Elimination of the suggested sources of error has largely been accomplished by using better calorimeters. An example of the response to this criticism is provided by the exchange between Shanahan[11, 12] and various authors[13, 14]. In every case, the suggested errors were either eliminated in future studies or shown not to be important. Additional examples of the errors and how they were corrected are described in my book.[5]

The amount of power can be increased by increasing the temperature, by the application of laser radiation, and by causing an electron current to pass through the material. The D/Pd ratio also affects power production when certain conditions are present. Perhaps in the future, other treatments will be found important.

Power can be produced when an active material of various types is exposed to electrolytic current, to low-energy plasma generated in a gas or liquid, and by exposure to D_2 or H_2 gas. In other words, the same behavior is observed regardless of how the fuel is delivered to the nuclear active sites.

Figure 1[15] shows a small example of successful efforts to make energy. The number of reported values is compared to the amount of power produced at room temperature by samples having a similar mass. Notice that the number of reports describing a successful attempt to make energy decreases as the amount of measured power increases. Most efforts make no energy at all. Even though this figure compares only a very small fraction of the total number of successful reports now available, this typical behavior reveals important information about the nature of the mechanism.

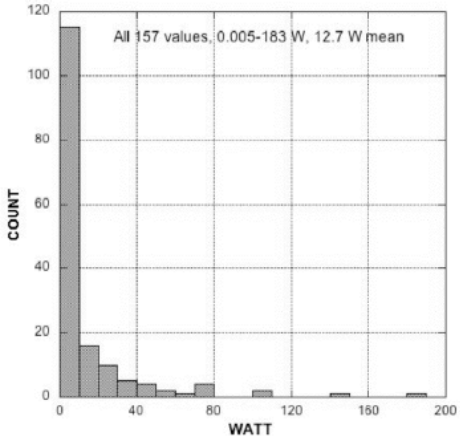

FIGURE 1. *Histogram showing the number of reported values for the measured power at room temperature produced by similar samples containing PdD. Values are taken from Table 2, "The Science of Low Energy Nuclear Reaction"[5] published in 2007.*

The shape of the histogram suggests a probability function could be used to describe the ability to produce conditions required to support the fusion process. Said another way, the shape suggests that no success is the most probable event with a small amount of power being much more probable than a larger amount. Thus, chance enters the picture by determining how much of the unique condition required for fusion to happen will form in a particular sample. The challenge is to increase the probability of forming the required conditions, thereby increasing the amount of nuclear power. Effective methods have been gradually discovered and applied, as I summarize in another paper.[7]

3.2 Effect of temperature,

The effect of temperature is important because the low temperatures known to affect energy production cannot directly influence a nuclear reaction. Instead, the temperature must affect a chemical process that limits the rate of the nuclear reaction. This realization has encouraged a search for this limiting process.

Most early studies were made at temperatures near 20°C even though F-P[16, 17] noted that the power could be increased by increasing the temperature. They correctly called this the "positive feedback effect" which, unfortunately, distracted from how the temperature affects the process. Over the years, other people[18] measured the power at various temperatures and found that, indeed, the amount of power increases with increased temperature. By using a very accurate calorimeter, I[19] made measurements over a wide range of temperatures and found that the temperature has the same effect when the measurement is made in either the electrolytic cell or in D_2 gas, as shown in Fig. 2. Other measurements, including those by other people[18], show that this temperature effect continues to temperatures at least as high as 500° C.

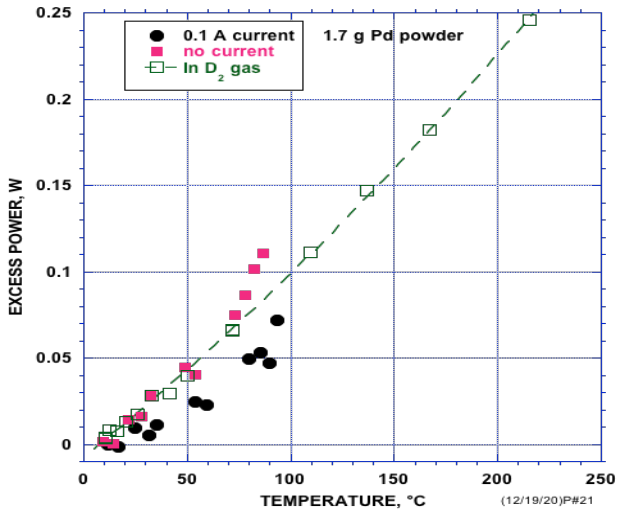

FIGURE 2. *Excess power is a function of temperature when a sample of PdD is heated in the electrolytic cell or when it is heated in D_2 gas. Production of power at the higher temperatures continued even after the current to the sample was stopped in the electrolytic cell. No detectable power was found at the lowest temperature.*

In chemistry, the slope of log power vs 1/T is identified as the activation energy for a process that limits the rate of a reaction. This value represents the amount of energy required to overcome an energy barrier to the final event. In this case, the activation energy for heat production appears to be related to the ability of the D or H to access the nuclear active sites by chemical diffusion,[19] both during the initial formation of the assembly and when the hydrogen nuclei are replaced after they have been converted to the nuclear product. This process requires the D or H nuclei to diffuse from their normal locations in the chemical structure to form an assembly where the nuclear process can take place. I showed that the activation energy for LENR under certain conditions is similar to the activation energy for the diffusion of D in PdD, suggesting that the diffusion of D controls the fusion rate under certain conditions.[19, 20] However, when the reaction with D_2 is used, the diffusion path can be complex. An example of this behavior is shown in Fig. 3 where the activation energy for the process occurring in an electrolytic cell is shown to be independent of the amount of power being produced. The activation energy and the amount of power are also independent of the D/Pd ratio as shown in Fig. 2. Here, the amount of power as well as the activation energy remained unchanged after the electrolytic current was stopped, thereby causing loss of D.

Access of nuclei to the active site also can be increased by having a flux of D atoms pass through the nuclear active region, as demonstrated by McKubre et al.[21].

Based on years of experience, samples that produce no excess energy at a low temperature will frequently produce energy when heated. This experience suggests that cold fusion is easier to produce than the many apparently failed measurements at room temperature would suggest.

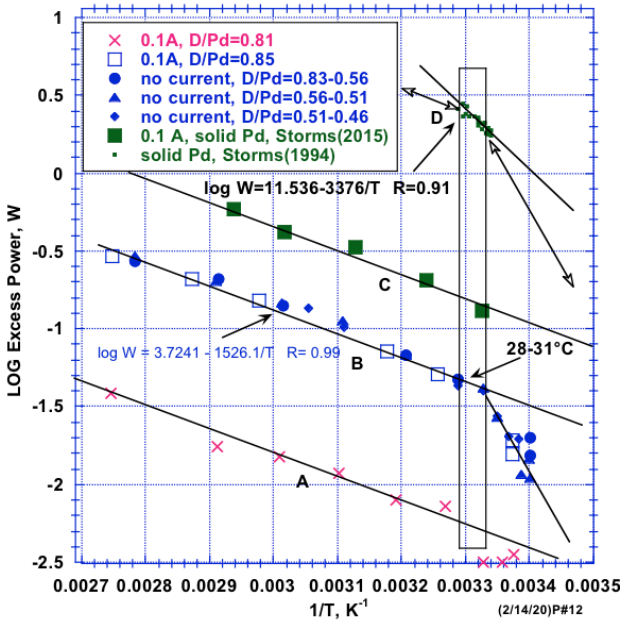

FIGURE 3. *Comparison between the behaviors of different samples of solid and pressed powdered Pd when heated in an electrolytic cell. The designations A, B, C, and D apply to independent measurements. The lines drawn through each measurement are parallel, showing that each has the same activation energy.[19, 22]. The study labeled "D" fell in the transition temperature region between two different values for the activation energy, designated as Storms(1994)[23]*

3.3 Effect of D/Pd ratio

A change in the D/Pd ratio has many effects, only two of which are noted here as being important. The bond energy between the D or H atoms decreases as the D(H)/Pd ratio is increased.[24] This makes the D or H more energetically available to form another structure outside of the crystal, such as the assembly required to support the fusion process. In addition, the crystal expands as D or H is added. This expansion can cause gaps to form around embedded particles, as is described in a later section. This process might have caused the power to increase when a special batch of Pd wire was studied by McKubre et al. [25], as shown in Fig. 4. A similar behavior was reported by Kamimura et al.[26]. However, a large D/Pd ratio is not always required to cause the production of power, as described by Storms[8] and shown in Figs. 2 and 3. Why some samples are sensitive to the D/Pd ratio and some are not is an important question answered in a later section.

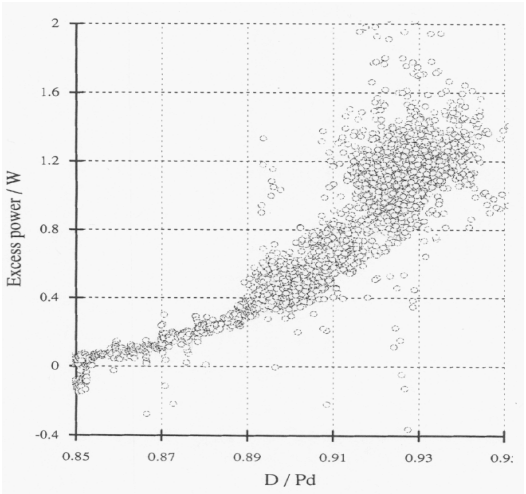

FIGURE 4*. Effect of D/Pd ratio on power production when an active batch of Pd wire was reacted in an electrolytic cell near 20° C. McKubre et al. [25]*

3.4 Effect of laser radiation

The application of laser radiation to a material can have many effects, including causing an increase in the local temperature, making electrons more available, and stimulating phonon energy states[27]. Letts and Cravens[28] found that when PdD was coated with Au, extra energy would result when it was exposed to 669 nm laser radiation. Storms[29] demonstrated that laser radiation does not initiate the nuclear process but, instead, increases the reaction rate for a process already underway. This work also demonstrated that the Au coating was not necessary to produce excess energy.

Later, Letts et al.[30] applied two lasers having variable frequencies. Several beat frequencies were produced that they claimed increased the amount of power. This result has been used by Hagelstein[31] to support his phonon model. On the other hand, this study failed to see the single-frequency effect reported earlier. In addition, the replication of this work by Guffey et al.[32] failed to produce the claimed effect. Other people have

applied lasers with various frequencies that were able to amplify the amount of power without the need to apply a beat frequency, an example of which is reported by Tian et al.[33]. Consequently, the role of a special frequency, as claimed by Hagelstein and Letts, is still unknown.[27, 34]

Laser radiation is found to produce antistokes[35] and Maser[36] radiation. This radiation could be the result of changes in the chemical structure produced by the fusion reaction or be emitted directly from the nuclear process itself. Nevertheless, this behavior is consistent with the apparent coherent nature of the fusion process.

Although a laser can stimulate the nuclear process, why this happens is still unknown.

3.5 Effect of Applied Current

The amount of power produced by an electrolytic cell is found to increase when the electrolytic current is increased. This effect was explained to result from either the resulting increased temperature or the increased D/Pd ratio.[5, 37] Increased power is also produced when current is passed through PdD in D_2 gas. This behavior was attributed to electro-migration, with D^+ being concentrated at the negative electrode, thereby increasing the local fusion rate at this location.[38]

Tanzella et al.[39] and the patent by Godes[40] describe the use of pulsed current with a very fast rise time to stimulate the heat-producing process in a complex solid structure. The pulsed current was proposed to cause free neutron formation followed by the formation of ^4H.

Celani et al.[41] applied pulsed current to the electrolytic cell to cause the excess power to increase. They later [42] used DC to heat Constantan wires that were bent into complex shapes. Additional excess power was produced when a pulsed current was added. The method was justified by an explanation too complex to discuss here.

Staker [43] caused DC to pass through a wire of Pd when it was electrolyzed in a conventional electrolytic cell. He found this current would increase the amount of power. Unfortunately, he used this behavior to justify a proposed change in the phase relationship in the Pd-D system, for which no other evidence exists.[44]

These explanations may require a reexamination, as is done in Section 5.0.

Meanwhile, in spite of the conflicting explanations, an applied current appears to have an important effect on the amount of power. Thus encouraged, I undertook a study of this effect, which is described here in order to encourage a more detailed study in the future.

A solid Pd was plated with Pd to produce local islands of a complex structure, as described by Gordon and Whitehouse (G-W)[45]. Figure 5 shows how the Pd was cut to allow the current to access most of the material. The sample was placed in a cell containing D_2 gas at about 0.5 atm and heated as shown in Fig. 6. The small amount of power added by the current was subtracted from the power being produced by the sample. This power is too small to change the temperature. In each case, DC passing through resistance wire surrounding the cell is used to increase the temperature.

It's important to note that the effect of applied current is large and shows an increased effect as the current is increased, as shown in Fig. 7. This variable has the potential not only to increase the amount of power but could be used to provide a rapid response to a variable load. Also, this variable is independent of temperature, and the

effect of applied temperature is independent of the current. In other words, the effect of these two variables results from two different and independent processes with applied current having the greater effect. Later studies demonstrated that the Pd deposit was not necessary for the current to increase the amount of power. The resistance was used to calculate the average D/Pd ratio using the equation provided by McKubre and Tanzella[46].

A current reversal after the study caused no change in excess power. This behavior suggests the concentration change caused by electromigration did not have a significant effect on excess power. This preliminary study needs to be repeated to determine the effects of a magnetic field, pulsed DC or AC, and current density. The reason why current has a major effect on power is explained in a later section.

FIGURE 5. *Sample of Pd coated with electrodeposited Pd and cut to allow the passage of a current through the metal. The cross-section through which the current passes is about 1 mm x 3 mm. The Pd weighs 2.5 g. (To be published)*

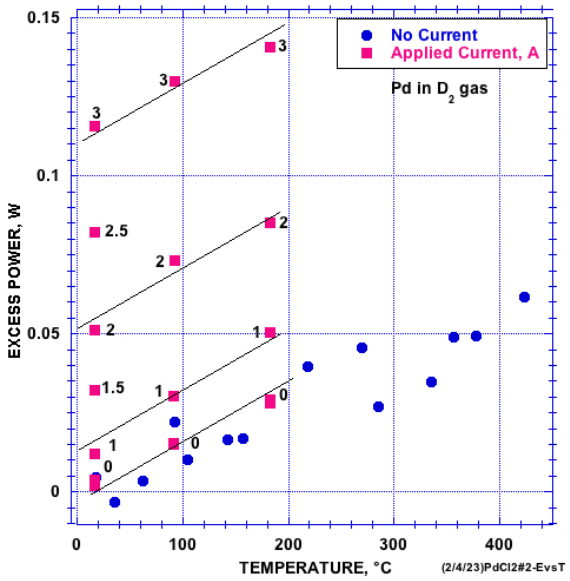

FIGURE 6. *Effect of a steady DC passing through PdD at various temperatures in D_2 gas. The amount of applied current is shown in units of ampere(A). The values for "no current" were obtained first followed by the values designated as "applied current".*

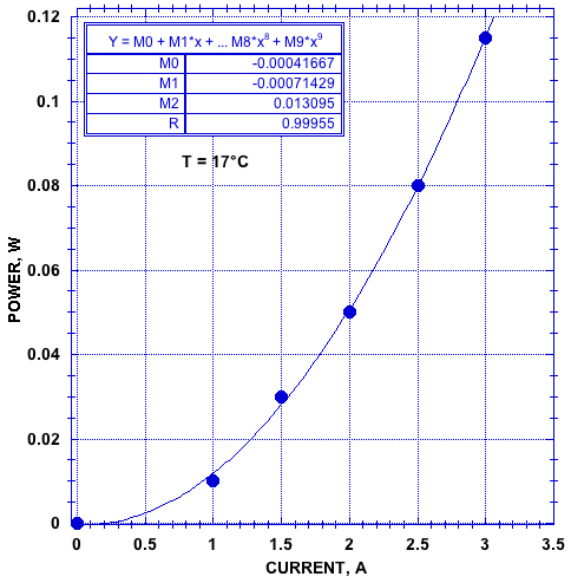

FIGURE 7. *Excess power as a function of applied current at 17°C. Notice that no power is detected in the absence of applied current.*

3.6 Helium production

Helium was expected and then found as a fusion product. But unlike the helium made by high-energy fusion (hot fusion), the helium nucleus produced by cold fusion remains intact and is measured as He gas. This creates a problem because the proposed nuclear reaction has no obvious way to conserve momentum when the nuclear energy is dissipated. Two or more nuclear products are required to conserve momentum, which are not formed according to the basic reaction as written. Therefore, something else must be emitted along with the He or with the ^4H, as explained in Section 4.2.3. Also, the description must explain why the energy released by low-energy fusion does not destabilize the He nucleus.

The fusion of D+D results in $2.6x10^{11}$ He/watt-sec,[10, 15, 47] as is calculated from the change in mass using $E=mc^2$. When the amount of measured energy is compared to the amount of measured helium and plotted as the He/watt-sec ratio, Figure 8 results. This histogram compares sixteen separate measurements obtained from four independent studies of the helium found in the gas that is generated in an electrolytic cell using a PdD cathode. Unfortunately, the helium trapped in the cathode was not measured. Therefore, the ratio is expected to be smaller than the true value as is, indeed, the case. In addition, a pattern of values is obtained that is consistent with an error function, as would result from the expected random errors in each measurement. Because the amounts of energy and helium are obtained from independent measurements, the good agreement indicates that both energy and helium came from a common source rather than from an accidental combination of random errors in the separate measurements of energy and helium.

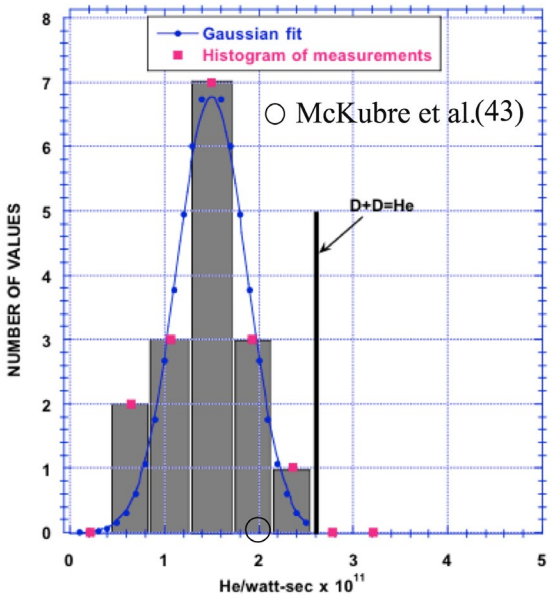

FIGURE 8. *Histogram of 16 measurements by four independent studies showing the amount of helium divided by the amount of energy produced by electrochemical cells containing D_2O. A Gaussian error function is fit to the distribution of values. The ratio based on the mass change for the fusion reaction $D+D=^4He$ is shown.[47] The value obtained by McKubre et al. resulted from a sample of charcoal on which a small amount of Pd was deposited. This sample was heated in D_2 gas near 243°C.*

Unlike the measurements compared in Figure 8, McKubre et al.[48] measured the helium produced by a sample of charcoal containing small particles of Pd heated in D_2 gas. The amount of generated power was measured using two different kinds of calorimeter: gradient and differential. The amount of helium was measured using a mass spectrometer. An air leak being the source of helium is eliminated because the amount of helium eventually exceeds the concentration in the air. The resulting relationship between energy and helium is shown in Fig. 9 as the amounts of helium and energy increased over time. Good agreement with other measurements is shown when the average He/watt-sec ratio (Gradient in Fig. 9)) of $2.0\pm0.8\text{x}10^{11}$ is compared to the values shown in Fig. 8. As expected, this comparison shows that less He was retained by the smaller amount of Pd present as small particles compared to the amount retained when larger pieces of palladium were used. The helium retained in this sample could be flushed out under a vacuum by repeatedly reacting with D_2.

In summary, the He/energy ratios produced during electrolysis near 20° C are consistent with an error function typical of behavior observed when independent measurements of any kind are made. As you can see, nearly the same He/energy ratio results when particles of Pd react directly with D_2 gas at high temperatures and when solid Pd reacts with D^+ in an electrolytic cell near room temperature. In other words, the behavior is typical of a universal process that does not depend on the method used to cause the fusion reaction.

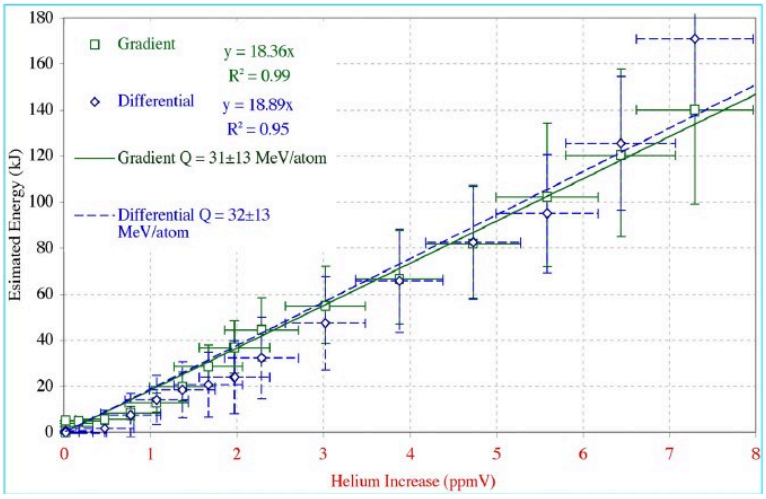

FIGURE 9*. Energy and helium were made by a special batch of coconut charcoal to which 5% Pd was applied as fine particles and heated near 243°C in D_2 gas while energy and helium were measured, as reported by McKubre et al. [48]*

3.7 Tritium production

Tritium is a minor nuclear product that is produced by LENR on rare occasions when certain conditions are present. Nevertheless, its occasional presence demonstrates that an unusual nuclear process can take place in a "conventional" material. Unlike the tritium that results from high-energy fusion (hot fusion), this tritium is not accompanied by an equal number of neutrons. Instead, the T/n ratio favors tritium, as shown in Fig. 10. Whether the wide range in values results from an error or because another variable is operating is important to determine. This question is discussed in a later section.

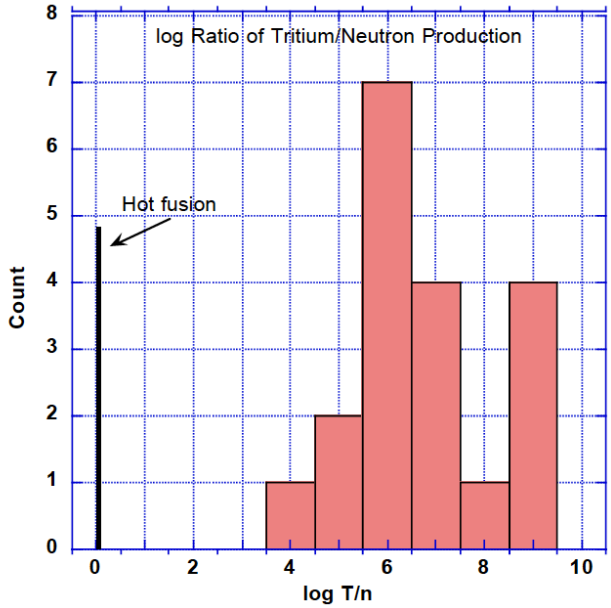

FIGURE 10. *Histogram of published measurements of the log tritium/neutron ratio. The measured log T/n resulting from hot fusion is also plotted. The values are from Table 6, "The Science of Low Energy Nuclear Reaction".[5]*

3.8 Radiation emission

Radiation dissipates energy from most nuclear events. Although frequently sought, radiation is seldom detected outside the apparatus when LENR occurs. This apparent absence of energetic radiation has caused much confusion and speculation about how nuclear energy is dissipated and how momentum is conserved. However, closer examination has shown that radiation is, indeed, emitted but with too little energy to easily escape the apparatus. In addition, this radiation has some very unusual characteristics, as described below.

This absence of dangerous radiation makes the energy from this source very safe and useful.

3.9 Ion emission

People naturally assumed the observed helium gas (Fig. 8) was emitted with most of the nuclear energy, in the manner of normal alpha emission. Karabut et al.[49] measured the ion spectrum produced by gas discharge in D_2. A silicon barrier detector (SBD) was used to determine the ion energy and the presence of energetic ions was confirmed using CR-39. The energy spectrum consisted of many separate peaks with nearly equal separation, the intensity of which decreased as the energy increased. Most of the energy was in the range between 1 MeV and 6 MeV. This radiation continued after the gas discharge was turned off, revealing a sustained fusion process. Therefore, the apparent emission was not the result of electrical "noise" produced by the discharge. They assumed this radiation resulted from alpha emission because ^{4}He was detected in the Pd cathode after the study. Some tritium was also detected in the gas along with a small neutron flux during the discharge. In addition, they[50] measured the photon energy and found the radiation to have laser-like behavior (Fig. 14). The energy suggested the emission resulted from a nuclear mechanism as well as X-rays. Some of this radiation even resulted from radioactive decay occurring over many hours. All of these measurements were made while excess energy was being recorded. Unfortunately, these measurements do not allow a comparison with other measurements such as shown in Figs. 8 and 10. Nevertheless, the behavior is not typical of a "normal" nuclear process.

Eight years later, Storms and Scanlan[51] measured the ion spectrum (Fig. 11) produced by gas discharge while also using a silicon barrier detector. Inserted absorbers were used to reveal the true nature of the ions and to demonstrate that they were not the result of "noise" created by the electric discharge. Electronic noise would not be changed by the insertion of the absorber. Instead, the absorber produced a reproducible change in the measured energy of each peak that was then used to identify the element being emitted, as described below.

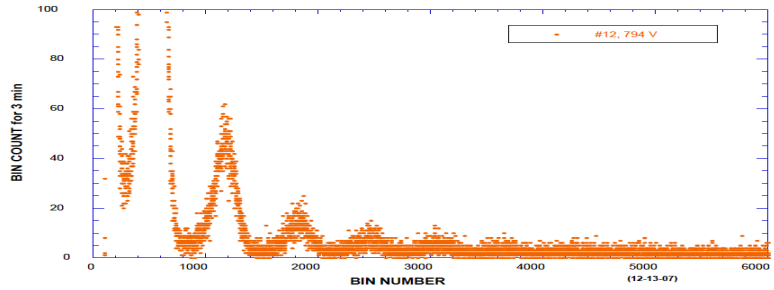

FIGURE 11. *A typical spectrum is produced during gas discharge when either H_2 or D_2 is used. The bin number was calibrated using the energetic alpha emitted from Po^{210}.*

Confidence in this measurement and the one reported by Karabut et al.[49] is justified by the good agreement between the energy of the radiation and the characteristics of the spectrum.

The measurements reported by Storms and Scanlan[46] have six major features.

1. The energy was emitted in equally separated peaks as shown in Fig. 12.
2. The number of ions in each peak decreased as the amount of energy increased, as shown in Fig. 13.
3. The spectrum is unchanged when either H_2 or D_2 is used.
4. The energy change that occurs when absorbers are inserted demonstrates the ions are an isotope of hydrogen, not helium, and the peaks are not the result of electrical "noise".
5. The ion energy is too large to have resulted from a chemical process.
6. Only a fraction of the energy released by a fusion reaction is contained in this radiation.

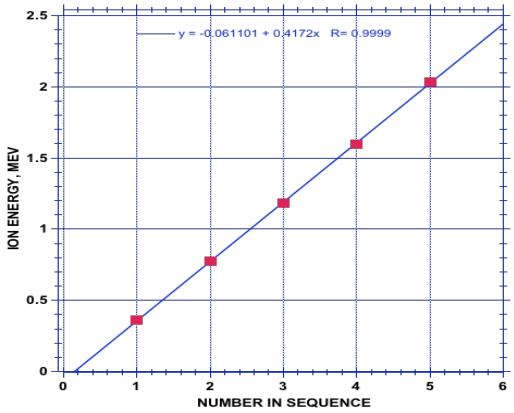

FIGURE 12. *The relationship between the sequence in the spectrum and the ion energy when the first peak is given a value of 1. The values are obtained from Fig. 11.*

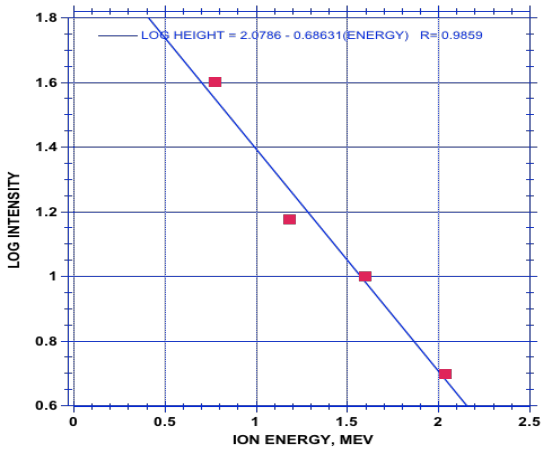

FIGURE 13. *The relationship between log intensity and ion energy. The intensity is given as a relative value. The values are obtained from Fig. 11.*

`The measured energy of an emitted ion is determined by how much material the

ion had to pass through to reach the detector. Ions made deeper than a few microns from the surface would not be detected. Also, if the ions were coming from many sources located at different depths, the spectrum would be smeared with each peak having a wide range in values. Instead, the well-defined peaks indicate the measured ions are coming from a single source located very near the surface. The similar width of each peak would result from a small but similar amount of scattering experienced by each ion. Of course, other sites might be producing ions but these would be located too deep for the ions to reach the detector.

When the energy is plotted as a function of the sequence (Fig. 12), the straight line extrapolates to zero at point #0. This indicates that very little energy is removed during the exit from the emitter and that the peak labeled #1 represents the lowest energy in a sequence being generated by the fusion process. Why each peak has the same energy difference of 0.417 MeV from its neighbor is still a mystery. It's perhaps worth noting that the mass of a stationary electron has an energy equivalent of 0.511 MeV. If the kinetic energy of the ^{4}H were the result of the conversion of the electron mass into energy, the value would be expected to be less than the true amount of energy, as is the case, because some would have been lost as the hydrogen ion passed through the material on its way to the surface. The mystery is increased because the ion energy has no clear relationship to the 23.8 MeV that was generated when the ion formed as the result of fusion. An explanation is suggested in the next section.

When the relative intensity is plotted as a function of energy (Fig. 13), an exponential relationship is revealed. This suggests the probability of forming an ion having the measured energy decreases as its energy increases. Although this behavior is yet to be explained, it reveals, once again, the unique complexity of this nuclear process.

The very similar behavior of H_2 and D_2 is an important surprise. This suggests that the same nuclear product can result from both reactants. This behavior does not eliminate other nuclear products from being produced at the same time. These emissions would not have been detected because their energy would not fall within the range of the SBD. An explanation is explored in a later section.

Storms and Scanlan[46] determined the nature of the ions by determining the change in energy produced when various absorbers were inserted. The change in energy was compared to that described in the NIST tables (NSRDS-NBS29) to identify the element being emitted. The emissions were shown to be consistent with the ions of a hydrogen isotope, not helium! However, at the time the work was done, the emission of ^{4}H, which is consistent with the observed behavior, was not considered. The role of this nuclear product is explored in a later section.

When D fuses, 23.8 MeV of energy is released that must be dissipated while momentum is conserved. The emitted nuclear product has only a fraction of this energy. Where is the missing energy? Also, the simultaneous emission of two particles is requited to conserve momentum. Where is the radiation that carries the remainder of the momentum? Why is the energy dissipated as many discreet energies? These questions add to the growing list an explanation must answer.

3.10 Photon emission

Karabut et al.[35] used photographic film to record highly focused beams of photons being emitted from the cathode. The pattern of behavior was similar to when

either 0.5 mm of aluminum or 2 mm of lead were placed between the cathode and the photographic plate, an example of which is shown in Fig. 14. Apparently, photons having a wide range of energy are emitted as tightly focused beams in random directions with different intensities. Szpak et al.[52] also used photographic film to detect photon radiation that appeared to be emitted from a single well-defined source, but in this case when an electrolytic cell is used. Once again, similar unusual behavior is seen when cold fusion is produced using two different methods by independent studies.

Because people would not expect to see highly focused beams to result from a nuclear process, methods able to detect focused radiation have not been used by most previous studies when photon radiation was detected, thereby missing this unusual behavior.

This behavior suggests a resonance process operates during the emission of photons that causes tightly focused beams to be emitted with a range of energy. The emission of ions and electrons would also be expected to have the same directionally with a similar spectrum of energies. This behavior has the potential to reveal the mechanism that releases nuclear energy.

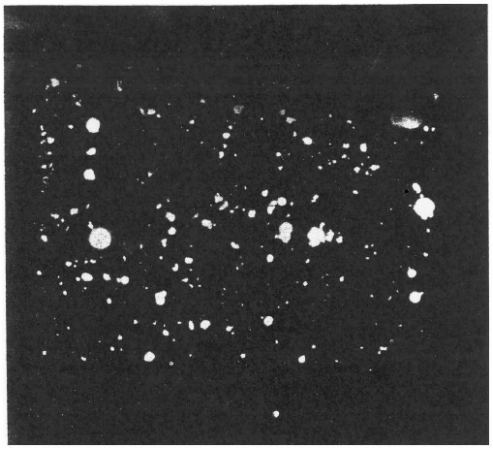

FIGURE 14. *Spots are produced on photographic film by photons that pass through 0.5 mm of aluminum. A similar pattern is produced when 2 mm of Pb is used.*

3.11 Electron emission

Electrons are normally emitted as decay products when a neutron changes into a proton within the nucleus. This process is called beta emission. Tritium is a beta emitter.

Recently, Gordon and Whitehouse (G-W)[45] measured a strong electron current being emitted from a deposit of Pd exposed to D_2 and from a deposit of Fe[53] when it was exposed to H_2. This emission is not the result of beta emission because it does not have a half-life. Instead, a steady current of energetic electrons is emitted from a material known to produce LENR. This measurement might provide the final missing piece of the puzzle and open the door to a new understanding of how nuclear energy is dissipated and how momentum is conserved when LENR occurs, as described below.

To test whether the electron emission is related to the excess power produced by LENR or not, I studied the relationship between electron emission and heat production using an active material and a calorimeter described in a previous paper.[19] The piece of Pd was activated by applying a layer of Pd using the codeposition method[54] (CoD), in

the manner used by G-W. This material was placed in D_2 gas with another electrode made of Pt that was used to collect the electron emission. This collector-sample assembly is shown in Figure 15. This assembly is sealed inside a quartz cell that can be heated using resistance wire wrapped around its outside. The current is measured as a voltage created across a resistor having a value of 0.1 Mohm.

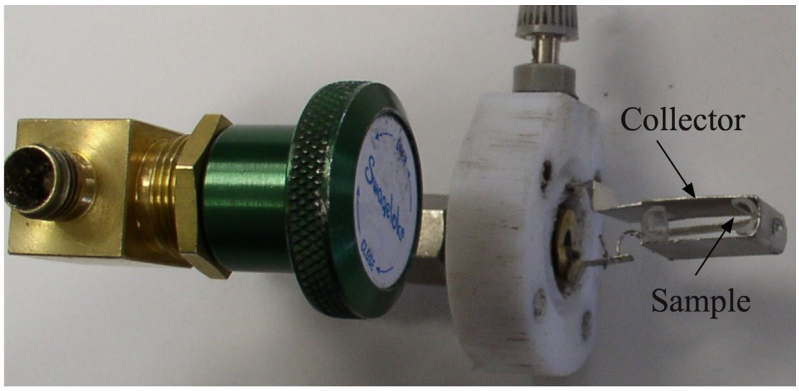

FIGURE 15. *Photograph of the sample-collector assembly.*

The material was heated in D_2 gas over a temperature range, as shown in Fig. 16. Excess power and electron current are both increased by increased temperature. This suggests both have a causal relationship with each other.

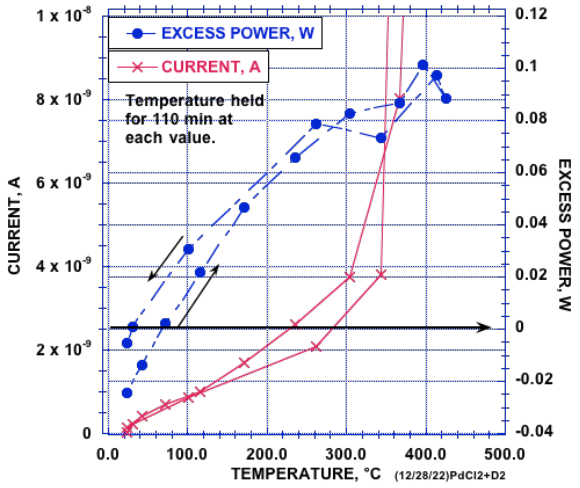

FIGURE 16. *Excess power and emitted electron current are measured as a function of temperature when co-deposited Pd is heated in D_2 gas. An external potential was not applied to the two electrodes. The arrows indicate the sequence of the measurements. The excess power was measured before the current was measured. The current was then measured when the temperature was increased and then decreased. The temperature is measured inside the cell near the sample.*

These measurements are more complex than a simple analysis would suggest. For example, electrons can escape from the sample only when the fusion reaction takes place very near its surface while heat energy can be measured regardless of where it is produced. With two different chemical environments being involved, the temperature and

applied current could influence these two locations in different ways. In addition, some current could result when ions are created in the D_2 gas by the emitted electrons. Some current could be added by thermionic emission as the temperature is increased above 350°C. The current measured at temperatures below 350° C is proposed to result only from those electrons emitted by a nuclear process that were able to leave the surface with an unknown amount of reduction in their original energy.

An effort was made to determine the energy distribution of the emitted current. The measurement was made by first applying 100 V between the sample and a collector in a cell containing D_2 while the cell was held at 298° C. The sample was given the indicated negative potential relative to the collector by connecting both to a power supply through a resistor. This potential would encourage all emitted electrons regardless of their energy to leave the surface and be collected as a current that would appear as a voltage across the resistor. Any ions in the gas would add to this current with a value that would change as the potential became less negative. The lack of a change in current as the voltage is decreased to zero indicates that gas ionization is not a source of significant current.

When the voltage is made positive relative to the emitter, electrons would be returned to the emitter when the applied potential is equal to or greater than the electron energy.The reduction in the emitted current (Fig. 17) as the voltage is made more positive relative to the emitter reveals that the electrons have a range of energy, most of which falls below 100 V. However, this energy may not be the true energy of the electrons being emitted from the nuclear process itself because the collected electrons might have traveled through enough material to cause a reduction in their energy by an unknown amount. Later measurements show that the energy of the emitted electrons can, on occasion, exceed 100 V. This amount of energy cannot result from a conventional source, such as a chemical reaction, because chemical reactions generate electrons with only a few eV of energy.

In addition, the power reported by Gordon and Whitehouse[45] represents only the power that is dissipated when the current is passed through a load. This power does not represent the total power carried by the emitted electrons because most of their kinetic energy would have been dissipated as heat when they were stopped in the electron collector. So, we once again have a question to answer, “How are such energetic electrons produced?”

Figure 18 shows how the current changes with time as the applied voltage is increased. After each voltage increase, the current decreases at a rate that depends on the amount of applied voltage, except at 100 V. Just as soon as 100 V is applied, causing a significant fraction of the current to be returned to the emitting surface, the amount of emitted current rapidly increases with a corresponding small increase in the amount of excess power. This behavior reveals another unexpected clue that is discussed in a later section.

Based on the measured power, the total number of fusion events is 3.9×10^{10}/sec. The number of electrons that manage to escape is 6.2×10^{11}/sec, which is the lower limit to the total number of electrons being released from the nuclear events. If these electrons resulted from the fusion process, why are so many more emitted compared to the number of fusion events? An answer is provided below.

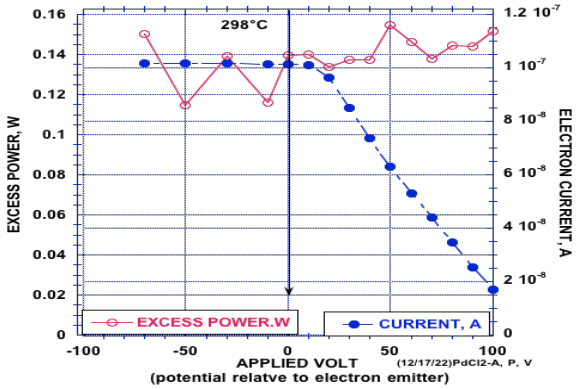

FIGURE 17. *Electron current and the excess power at a temperature of 298° C when the voltage between the emitter and collector is changed. The potential is shown relative to the emitter.*

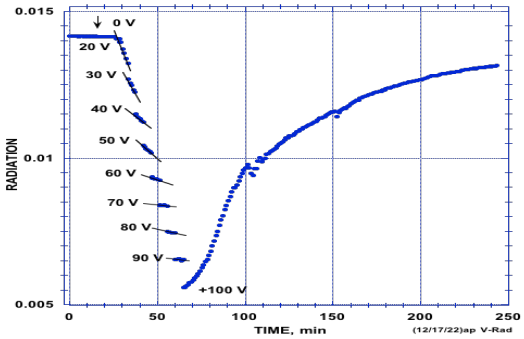

FIGURE 18*. Effect of time on the voltage measured across a series resistor when the voltage across the cell is changed as shown in Fig. 17. The radiation represents an arbitrary value for the current.*

4.0 PROPOSED MECHANISM

The pieces of the puzzle have been identified in the previous sections, so now is the time to fit them together. But first, a few assumptions have to be made. An assumption is a belief that cannot be proven but must be accepted on faith for a theory to move forward. The assumptions can be demonstrated to be plausible only after the proposed theory is found to be correct. If an assumption were wrong, all conclusions based on the assumption would also be wrong. Success depends on an assumption being applied only when necessary and the reasons why an assumption is used need to be clearly stated. In other words, the chosen assumptions will determine whether an explanation will be successful just like the assumption that the compass gives the correct direction from North would determine whether the correct path could be followed when exploring a wilderness.

4.1 Assumptions

The assumptions used here are listed below.

1. The Laws of Thermodynamics, phase theory, the rules governing crystal formation, as well as all chemical understanding, apply to LENR. Reason: LENR takes place in a chemical environment to which these rules apply.

2. The conservation of momentum, the rules governing Quantum Mechanics, and the conventional understanding of nuclear physics apply to LENR. Reason: LENR is a variation of conventional nuclear behavior.
3. The same universal mechanism and required conditions apply to all isotopes of hydrogen. The different isotopes of hydrogen produce different nuclear products by the same mechanism. Reason: All hydrogen isotopes have very similar chemical properties that control the assembly process.
4. The same universal nuclear mechanism operates during LENR regardless of the material being used as the host or its treatment. Reason: Nature typically has a single mechanism for causing the various phenomena.

4.2 Stages

As noted previously, four separate events take place in sequence, consisting of several chemical events followed by several nuclear reactions. Each event needs to be described as if it were an isolated mechanism. The nuclear event can be best considered an accidental consequence of a novel chemical arrangement involving electrons and hydrogen nuclei.

The presence of H or a mixture of D+H will cause different nuclear products compared to the D+D reaction but each reaction results from the same kind of mechanism (Assumption #3). This process also can result in secondary nuclear reactions, identified as transmutation reactions, that might produce radiation and various decay products. These radiations can be mistaken to result directly from the fusion reaction itself, thereby adding additional complexity and confusion. The secondary nuclear reactions are not discussed here.

4.2.1 Nuclear-active-environment *(NAE)*

LENR is proposed to involve a new kind of electron structure in which a nuclear process can take place without applied energy. The environment in which this assembly can form is rare. Nevertheless, the nuclear process will not happen unless this environment is available.

The unique location in which the nuclear reaction takes place is called the nuclear active environment (NAE). The number of such locations in a material determines the maximum amount of nuclear power that can be produced because the amount of NAE determines the maximum number of fusion sites. Because most Pd does not contain any NAE, most Pd will not support LENR, as has been frequently demonstrated. The challenge is to identify the NAE and then find ways to create more of it to increase the amount of nuclear energy.

Every location in PdD has been suggested by someone as the NAE, including the crystal structure itself, the D or Pd atom vacancies, various kinds of defects in the atom arrangement, and grain boundaries. The surface of small particles and small physical gaps are also proposed as possible sites. The correct identification of the NAE is critical to being able to create the required environment on purpose, to understand how LENR works, and eventually create a practical energy source. Therefore, a critical evaluation of the suggested sites is required.

When evaluating the suitability of a site, it's important to realize that simply having two D(H) occupy the site at the same time is not sufficient for fusion to occur.

Besides the D(H) nuclei, a very unusual and complex structure involving electrons must form. When formed, this structure must not conflict with the chemical conditions present at the site. Therefore, the site where fusion can occur has to have chemical characteristics that would not create this conflict. Sites within the lattice structure, such as vacancies, defects, or tetrahedral locations would violate this requirement because they are created by the rules governing the formation of the fcc structure. The formation of another structure would conflict with these rules. This consideration is so important and so difficult for people who do not understand the nature of chemical interaction, that I hope I can be forgiven for repeating the reasons so many different ways.

The tetrahedral site fails because each of these sites has the same chemical properties and, hence is chemically identical to all other tetrahedral sites. If the NAS could form in one site, it would form in all the other sites with equal probability, thereby making the fusion process very common for all samples of PdD, which is not the case.

Vacancy occupation fails for the same reason. Two kinds of vacancies exist in PdD(H). The first kind forms where atoms are missing in the D(H) sublattice, which results in the observed wide range of D(H)/Pd ratios as a variable number of vacancies are randomly filled by D+ or H+ ions. Each site contains only one D(H) with more than a single occupancy being caused only by the chance motion of the D(H) as a result of normal self-diffusion. If this chance occupancy resulted in LENR, the effect would be expected to be much more common and to occur in every sample of Pd regardless of its treatment.

Vacancies seldom occur in the Pd sublattice and are rarely formed under the conditions used to cause LENR. These vacancies are eliminated as the NAE because if the atom arrangement required for fusion to occur were chemically stable in a vacancy, the vacancy would not be a vacancy. Instead, all of the same vacancies would contain this stable structure as part of the normal atom arrangement, which would create a different atom arrangement without vacancies. In addition, the NAE would be very common and be located throughout the entire lattice structure, which is not the case. In addition, the claim by Staker[44, 55, 56] that vacancy tubes are present in PdD as the NAE is very weak because the claim by Fukai[57] on which this idea is based could not be replicated.[58] Because these tubes would have the same chemical properties as a Pd atom vacancy, their occupancy would suffer the same limitation.

This leaves cracks or gaps that are formed as the accidental result of stress relief. These gaps would contain a wide range of chemical conditions unlike those in the crystal structure. Because gaps are always present in material while LENR rarely occurs, the required conditions must rarely form in the gaps. This behavior suggests the gap must have a critical width and/or a critical chemical property that is seldom present. Only when this rare condition is present in a gap would a chemically stable assembly of hydrogen nuclei and electrons form at these locations.

Experience reveals that the conditions required to form NAE can be present in Pd at the time it is manufactured. This condition is even maintained throughout the material regardless of its subsequent treatment.[22, 59] As a result, when a piece of Pd is found to support LENR, all parts of the batch from which it came are also found to be active. The opposite is also true. Dead samples are found to result from batches in which all samples are dead. Also, very pure Pd is found not to support LENR. Certain impurities appear to be important. This overall behavior greatly limits the nature of the NAE when Pd is used.

Other active materials, of which many are known, would be expected to have different characteristics. The challenge is to find the universal characteristic that can be created in all materials. I have addressed this problem in a paper soon to be published.[8]

4.2.2 Nuclear-active-structure (NAS)

The actual arrangement of atoms and electrons that experience fusion is called the NAS. The NAS forms at special locations in the NAE. Each NAS assembles in the NAE, fuses, explodes, and then reforms, as shown by the video provided by Szpak et al. [60]. This video shows heat being produced as isolated small hot spots that wink off and on. The measured power results from the sum of the energy being made by this chaotic and random process operating at a relatively small number of isolated locations in an active material. The greater the number of NAS in the NAE, the more rapidly each HAS exploded, and the greater the number of NAE in the material, the more power would be produced.

For fusion to occur, the hydrogen nuclei in the NAS must achieve a separation small enough to allow their nuclear energy states to interact. People have focused on the behavior of hot fusion as a way to explain cold fusion. This is a false path for the following reasons.

In the case of hot fusion, the Coulomb barrier is overcome by the kinetic energy of each nuclei, usually in a very hot plasma. When the hot fusion reaction is instead caused to take place in a material by bombarding the material with ions having kinetic energy, the electrons present in the material can add local screening to increase the very small rate of the hot fusion reaction, especially at low kinetic energy, as shown in Fig. 19.[61, 62]

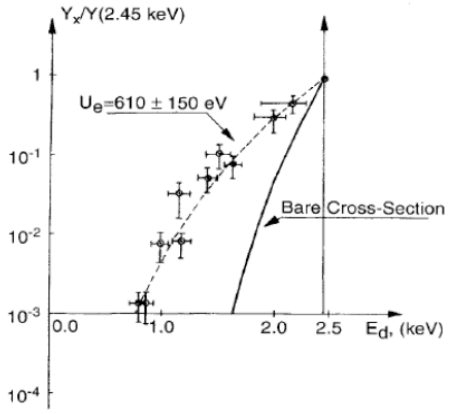

FIGURE 19*. The result of D+ bombardment of Ti with kinetic energy to produce the rate of hot fusion relative to when a kinetic energy of 2.45 KeV [63] is applied. A calculated value for the screening potential (U_e) is shown. The bare cross-section is obtained when fusion occurs in plasma. The absolute fusion rate at this energy is near the detection limit, to which electron screening adds very little to the very small fusion rate.*

In this case, the electrons near the site of each random encounter will slightly reduce the magnitude of the local barrier, with the amount of screening increasing as the kinetic energy is reduced causing a reduction in the approach velocity.

Although this screening effect is large, it is not large enough to fully compensate for the reduced reaction rate caused by the reduction in kinetic energy. At best, this behavior shows that electron screening of the hot fusion mechanism is possible in a chemical structure. This kind of screening does not apply to the cold fusion process during which the applied kinetic energy is essentially zero, the resulting He nucleus does not fragment, and the amount of screening is far greater.

In the case of cold fusion, the electrons must first concentrate near the hydrogen nuclei in sufficient numbers and in a structure that can reduce the Coulomb field enough for the nuclei to share their nuclear energy states. Now we have a problem because electrons are not known to concentrate this way. When electrons concentrate to form chemical compounds or crystals, the electron structure keeps the nuclei far apart. For LENR to occur, the electrons need to force the nuclei closer together. This requires a new kind of electron interaction. This realization is one of the important consequences resulting from this discovery.

4.2.3 Nuclear Products

Based on the data summarized in Fig. 8, ^{4}He is the main nuclear product from which the energy results. Storms and Scanlan[8] showed that helium is not emitted directly from the nuclear event. Instead, an isotope of hydrogen is emitted. Nevertheless, ^{4}He gas accumulates in the environment as nuclear energy is produced. How can these two facts be reconciled?

The only hydrogen isotope with the potential to decay into ^{4}He is ^{4}H. However, this isotope is known to rapidly decay by neutron emission when it has been formed at high energy.[64] Indeed, the decay is so rapid, doubt has been expressed as to whether the ^{4}H has been created at all. Nevertheless, the possibility that ^{4}H has a different decay mode when made in the absence of kinetic energy needs to be explored, especially given the measurements shown in Fig. 11. In addition, Meulenberg and Sinha[65] (M+S) used a theory to suggest that ^{4}H might decay into ^{4}He. This idea is accepted here but the formation of ^{4}H is proposed to occur by a mechanism different from the one M+S proposed.

How might ^{4}H be produced instead of ^{4}He? This question needs to be combined with another question. How can tritium be produced by the same mechanism to satisfy Assumption #3?

As noted in the previous description, an accumulation of electrons in the NAS is required to reduce the Coulomb barrier. After the electrons have been assembled around the hydrogen nuclei, they would have to interact with each other and with the nuclear energy states of the hydrogen nuclei. Let's assume that during this process, one of these electrons is captured in the nuclear product to form ^{4}H, as described by the first reaction listed in Table 1. Godes[66] also suggested the formation of this nuclear product but by a mechanism involving the direct formation of a neutron. Although a neutron is formed by the mechanism suggested here, this formation takes place in the nuclear product, which supplies the required energy, and avoids having to supply the energy of 0.78 MeV from the chemical environment, as is needed when a neutron is formed directly from p^+ and e^- in free space. The question is, "Can this mechanism produce all of the other known nuclear products?"

The other reactions, listed in Table 1, are obtained by applying Assumptions #3 and #4. In this way, the formation of tritium is explained by the fusion between H+ and D+ along with a captured electron. A similar reaction between two H+ would result in a deuteron. In summary, the overall process appears to convert one hydrogen isotope into another one as the result of fusion involving electron screening and electron capture. These proposed reactions could be tested as follows.

TABLE 1

Proposed reactants, nuclear products, and energy for each reaction produced by cold fusion[10]

(D+e+D) = ^{4}H = ^{4}He + e (fast decay) + ν	23.8 MeV
(H+e+D) = ^{3}H = ^{3}He + e (slow decay) + ν	4.9 MeV
(H+e+H) = ^{2}H (stable)	1.9 MeV
(T+e+D) = ^{4}H + **n** = ^{4}He + e (fast) + ν	<19 MeV
(T+e+H) = ^{4}H = ^{4}He + e (fast decay) + ν	<21 MeV

When H is caused to fuse without D being initially present in the NAE, the amount of tritium (^{3}H) would slowly increase as the first nuclear product (D) accumulates in the material and fuses with H. As the D concentration further increases, the D+D reaction would produce ^{4}H and its decay product ^{4}He. Consequently, the same nuclear emission would be detected when either pure H or D were used, as was observed by Storms and Scanlan[47]. The energy produced by this complex collection of reactions would be less than that produced by pure D+e+D, yet would still be significant.

But why does Ni appear to be required to make significant energy when only H is used? I suggest the resulting deuterium and tritium are more effectively retained in the NAE of Ni compared to Pd, thereby making them more effective as reactants. As a result, the amount of energy would be greater and the amount of detected tritium would be smaller than when Pd is used.

The few neutrons produced when tritium is present result from fusion between the tritium and deuterium nuclei. The wide range in the T/n values (Figure 10) would be caused by random variations in the D and T concentrations during the various studies. A careful study of changes in the T/n ratio while the concentrations of T and D are changed would reveal the true source of neutron emission.

Two more questions need answers. How is the momentum conserved without a second nuclear product being emitted and where is the energy observed to be missing from the emitted ^{4}H? The proposed answer is that the assembled electrons, which would interact with the nuclear energy states as their screening effect allowed fusion to occur, would acquire some of the resulting nuclear energy and dissipate it with momentum as the observed electron current. Although this kind of energy dissipation is unique and difficult to justify, it needs to be considered given the observed behavior. This description has several implications that can be explored to test the validity of this proposed mechanism.

Because the formation of the NAS requires both nuclei and electrons to assemble at the same location, the rates at which each can arrive at the NAS would determine the amount of power. This process would take time and be sensitive to those variables that

increase the availability of nuclei and electrons to the growing NAS. The availability of nuclei to the NAS is determined mainly by temperature and access to the source of D+ ions, as has been described previously[20]. I now turn to the effect of electron availability.

Electrons in a metallic conductor, such as PdD, have two different kinds of availability. The electrons that bond the atoms together in the crystal structure are tightly bound and unavailable. In contrast, the conduction electrons are free to move and to be captured by the NAS. Application of a voltage that causes the conduction electrons to move would increase the probability of such an electron encountering an NAE where it might be captured. This expected effect is shown in Fig. 6 where several different currents are applied at different temperatures. The temperature has very little influence on the effect of the current. In contrast, an increase in the current has an increasingly larger effect on the reaction rate, as would be expected if a large number of electrons had to be supplied to the NAS.

A magnetic field would be expected to increase the effect of the current because the path length of the electrons would be increased as they rotated around the magnetic lines of force, thereby increasing the probability of encountering a NAS.

This current would also cause D or H ions in the material to concentrate near the negative polarity as a result of electromigration, identified frequently as the Coehn Effect,[38] thereby further increasing the availability of nuclei at this location.

Support for this proposed mechanism is provided by Godes[39], Celani et al.[42] and Staker[67] who have applied a current to successfully increase the rate of power production. However, they explain the success by suggesting different mechanisms. The challenge is to determine which proposed mechanism is correct.

4.2.4 Predictions

The collection of behaviors allows several testable predictions to be made. These predictions can be used as a means to verify the explanation and as a guide for future studies.

1. Use of D that does not contain H will not produce tritium.
2. Use of H that does not contain initial D will eventually produce tritium at an increasing rate as the amount of D increases as a result of the initial fusion reaction. The neutron flux will also increase as the amount of tritium and deuterium increases.
3. The use of either D or H will produce nuclear energy with H producing less power than D when the same number of NAS is present.
4. The use of either D or H will produce the emission of ^{4}H and the formation of ^{4}He, its decay product by fast beta decay.
5. An electron current passing through the NAE will increase the fusion rate.
6. A flux of hydrogen isotopes passing through the NAE will increase the fusion rate.
7. The NAE can be constructed using nano-machining of a conducive metal to which is applied a suitable source of deuterium, an electric current, and increased temperature.
8. All of the radiation consisting of photons, ions, and electrons is emitted as tightly focused beams in random directions with a complex spectrum of energies.

9. Most of the nuclear energy is dissipated by a large number of electrons, each of which has only a small fraction of the total and a coherent relationship to the other electrons.

5.0 DISCUSSION OF THE NUCLEAR PROCESS

Because the conditions required to cause LENR are unique to nuclear physics, the process has been very difficult to accept and understand. Enough evidence has now been acquired to show that LENR is real and not a mistake. The next step requires this evidence to be assembled into a useful description of HOW the process works. For this goal to be accomplished, we need to make the critical measurements with greater skill and to test the suggested predictions. Only then would a mathematical description of WHY the nuclear mechanism works be useful. This necessary goal is presently handicapped by the absence of reliable observations having universal acceptance. This paper is provided as a guide to show how such information could be obtained and how the present knowledge is related through a logical description.

The promised benefit of this clean energy can only be realized after the required NAE and the nuclear mechanism are correctly understood and can be caused with reliability. In addition, cold fusion requires an answer to several difficult questions.

Cold Fusion produces a nuclear product, ^{4}He, that does not fragment even though it would contain about the same amount of energy as would result from hot fusion, which does cause the ^{4}He to fragment even when it is produced in a chemical environment. What prevents the resulting nucleus from fragmenting when cold fusion occurs?

The second question involves how the Coulomb barrier is reduced without having to apply kinetic energy. As described in previous sections, this process is proposed to involve an assembly of electrons.

Those electrons that could interact with the nuclear energy states would be able to dissipate a small part of the mass-energy as they were emitted from the assembly after the fusion reaction had made mass-energy available. This emission could be viewed as a nuclear explosion that sent the surrounding electrons in all directions. As the last of the electrons were emitted, one would be captured by the final nuclear energy state to form ^{4}H. As a result, this final nuclear product would not fragment because the excess energy could be released by beta emission.

Let's now go deeper into the rabbit hole. Has such an electron assembly been suggested? Mills[68] provided a partial description of this process in the form of the hydrino. Rathke[69] and Meulenberg[70] add further details to the understanding of how an electron or perhaps many electrons might acquire a condition of direct energy interaction with the nucleus itself. The resulting assembly could be viewed as a large nucleus containing electrons in energy states normally not present in a nucleus nor as normal chemical energy states. Has a suitable structure been observed?

As described by Shoulders[71], the structure he discovered would have the required characteristics, except it did not experience fusion when he made it in air. Perhaps the assembly did not support fusion because it did not contain a hydrogen isotope. He called this an EVO. Fox[72] and Jin[73] explored the idea in greater detail. Rambaut[74] describes this electron structure as a magnetic monopole. Hubler[75] provides a different explanation for the same behavior. Ball lightning has a similar characteristic but on a larger scale.[76-79] Because this structure, in its several forms, has

been made and studied using electric discharge in a gas, its ability to form in a solid chemical environment must be assumed.

This slow fusion process would be unique and not previously observed because all previous nuclear interactions have involved the application of kinetic energy, which would force the nuclear energy to be quickly released as energetic nuclear products or more slowly as radioactive decay by a different mechanism. Radioactive decay seldom results from cold fusion because all the energy has been released by electron emission, except when ^{4}H and ^{3}H form. The remaining energy released by beta decay would be small compared to the initial release, thereby limiting the amount of energy lost energy to the resulting neutrino.

Nevertheless, the final nuclear product is found to contain some kinetic energy, the value of which is shown in Fig. 12. Why this energy has values that have a fixed difference is still unknown and needs to be explained.

6.0 SUMMARY

Normally, the chemical energy states do not interact DIRECTLY with the nuclear energy states. This means that a condition not present in a normal chemical structure has to be created somewhere in the chemical structure before fusion can occur. This unique structure is proposed to form only in physical gaps having a critical size in the nanometer range. These gaps can be produced by many different treatments and in many different kinds of materials. This structure is proposed to consist of four or more hydrogen nuclei and many electrons. The creation process is consistent with the rules that apply to chemical processes because, initially, the process does not anticipate a nuclear interaction.

To cause fusion, this structure must allow at least two D to get close enough for their nuclear energy states to interact. At least, two nuclear products resulting from the fusion mechanism must be created at the same time to allow conservation of momentum when the released mass-energy is dissipated. The electrons that cause this reduction in separation as the result of shielding or tunneling would interact with the nuclear energy states. As a result, as fusion happens, some of these electrons would have access to the mass-energy and be able to dissipate this energy as kinetic energy and momentum.

Said another way, the electrons assemble in such a way to allow them to interact with the Coulomb barrier between the hydrogen nuclei located within the cloud. As the barrier between the assembled nuclei is reduced, the nuclear energy states start to interact. Because the electrons are causing this effect, they therefore interact with the combined nuclear energy states by sharing their energy. As the nuclei continue to merge, energy gradually accumulates in the combined energy states until it becomes too great for the energy structure to support, whereupon the assembly "explodes". One of the surrounding electrons is captured by the combined nucleus to form ^{4}H when D is used. The ^{4}H ion is emitted with a small fraction of the total energy of 23.8 MeV/event, as shown in Fig. 11. This very unusual behavior reveals why this process has been so difficult to understand.

Because the electrons are not emitted by the beta decay mechanism, neutrinos are not produced. Nevertheless, low-energy neutrinos would be produced by the normal beta decay of ^{3}H and ^{4}H, but only after most of the energy has been previously dissipated by a different mechanism, thereby leaving very little energy for the neutrino to carry away.

This kind of electron structure might form in many materials but be ignored when nothing unusual happens. The sites would be made visible by a nuclear process only when an isotope of hydrogen is made available and the resulting nuclear power is great enough to be detected. In other words, this process might have always occurred at a rate too low for it to be detected until F-P made such a search important enough to demand attention. A description based on a similar assembly of atoms and electrons has been suggested by Goncharov and Kirkinskii[80].

The nuclear process is proposed to convert one hydrogen isotope to another. The initial formation of ^{4}H from D-e-D fusion produces ^{4}He by rapid beta decay. Tritium formed from D-e-H fusion produces ^{3}He by slow beta decay. A few neutrons are made when the tritium fuses with ^{2}H. The same mechanism applies equally to all isotopes of hydrogen with only the nuclear product being affected by the isotope being caused to fuse.

What is stopping this potential source of clean energy from being used on a large scale? After all, a huge and expensive structure is not required, unlike hot fusion. Instead, LENR needs only a special condition located within an ordinary material, such as palladium or several other materials, to be produced. The required conditions might also be made in large amounts with reproducible behavior using nano-machining. The discovery of how to make LENR useful has been slow only because the effort to understand has been trivial compared to the difficulty. Nevertheless, this problem is being slowly solved. Hopefully, this paper will accelerate the effort.

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REFERENCES

[1] M. Fleischmann, S. Pons, M. Hawkins, Electrochemically induced nuclear fusion of deuterium, J. Electroanal. Chem. 261 (1989) 301-8 and errata in Vol. 263, 187-8.
[2] D. Clery, ITER's $12 billion gamble, Science 214 (2006) 238.
[3] J.R. Huizenga, Cold fusion: The scientific fiasco of the century, second ed., Oxford University Press, New York, 1993.
[4] S.B. Krivit, Fusion Fiasco, Explorations in Nuclear Research, Vol. 2-The behind-the-scenes story of the 1989-1990 fusion fiasco, Pacific Oaks Press, San Rafael, CA, 2016.
[5] E.K. Storms, The science of low energy nuclear reaction, World Scientific, Singapore, 2007.
[6] E.N. Tsyganov, V.M. Golovatyuk, S.P. Lobastov, M.D. Bavizhev, S.B. Dabagov, Registration of energy discharge in D + D =4He* reaction in conducting crystals (simulation of experiment), Nucl. Instr. and Meth. in Phys. Res. B 309 (2013) 95-104.
[7] E.K. Storms, The Material Science Aspects of Low Energy Fusion, in: www.LENR.org (Ed), 2023.

[8] E.K. Storms, The Nature of Cold Fusion (Cold Fusion Made Simple), Solid State Energy Summit, ICCF24, www.LENR.org, Mountain View, CA, 2022.
[9] E.K. Storms, B. Scanlan, Radiation produced by glow discharge in deuterium, in: J. Rothwell, P. Mobberley (Eds), 8th International Workshop on Anomalies in Hydrogen / Deuterium Loaded Metals. 2007., http://www.iscmns.org/catania07/index.htm. The International Society for Condensed Matter Science, Catania, Sicily, 2007, pp. 297-305.
[10] E.K. Storms, The explanation of low energy nuclear reaction, Infinite Energy Press, Concord, NH, 2014.
[11] K.L. Shanahan, Comments on 'Thermal Behavior of Polarized Pd/D Electrodes Prepared by Co-Deposition', Thermochim. Acta 428 (2005) 207-12.
[12] K. Shanahan, Reply to "Comment on papers by K. Shanahan that propose to explain anomalous heat generated by cold fusion", E. Storms, Thermochim. Acta, 2006, Thermochim. Acta 441 (2006) 210-4.
[13] E.K. Storms, Comment on papers by K. Shanahan that propose to explain anomalous heat generated by cold fusion, Thermochim. Acta 441 (2006) 207-9.
[14] J. Marwan, M.C. McKubre, F. Tanzella, P.L. Hagelstein, M. Miles, M.R. Swartz, E.K. Storms, Y. Iwamura, P.A. Mosier-Boss, L. Forsley, A new look at low-energy nuclear reaction (LENR) research: A response to Shanahan, J. Environ. Monit. (2010).
[15] E.K. Storms, The status of cold fusion (2010), Naturwissenschaften 97 (2010) 861.
[16] S. Pons, M. Fleischmann, Heat after death, Trans. Fusion Technol. 26 (1994) 87-95.
[17] S. Pons, M. Fleischmann, Etalonnage du systeme Pd-D_2O: effets de protocole et feed-back positif. ["Calibration of the Pd-D_2O system: protocol and positive feed-back effects"], J. Chim. Phys. 93 (1996) 711 (in French).
[18] Z.M. Dong, C.L. Liang , X.Z. Li, S.X. Zheng, Temperature Dependence of Excess Power in Both Electrolysis and Gas-loading Experiments, J. Cond. Matter. Nucl. Sci. 29 (2019) 85-94.
[19] E. Storms, Anomalous Energy Produced by PdD, J. Cond. Matter. Nucl. Sci. 20 (2016) 81-99.
[20] E. Storms, The Nature of the D+D Fusion Reaction in Palladium and Nickel, JCMNS 36 (2022) 377-94.
[21] M.C.H. McKubre, F.L. Tanzella, Flux Effects in Metal Hydrogen Loading: Enhanced Mass Transfer, J. Cond. Matter Nucl. Sci. 15 (2015) 1-10.
[22] E.K. Storms, Measurements of excess heat from a Pons-Fleischmann-type electrolytic cell using palladium sheet, Fusion Technol. 23 (1993) 230.
[23] E.K. Storms, Some characteristics of heat production using the "cold fusion" effect, Trans. Fusion Technol. 26 (1994) 96.
[24] E. Storms, The Enthalpy of Formation of PdH as a Function of H/Pd Atom Ratio, J. Cond. Matter. Nucl. Sci. 29 (2019) 275-85.
[25] M.C.H. McKubre, S. Crouch-Baker, A.M. Riley, S.I. Smedley, F.L. Tanzella, Excess power observations in electrochemical studies of the D/Pd system; the influence of loading, in: H. Ikegami (Ed) Third International Conference on Cold Fusion, "Frontiers of Cold Fusion", Published by: Universal Academy Press, Inc., Tokyo, Japan, Held at: Nagoya Japan, 1992, pp. 5.

[26] H. Kamimura, T. Senjuh, S. Miyashita, N. Asami, Excess heat in fuel cell type cells from pure Pd cathodes annealed at high temperatures, in: M. Okamoto (Ed) Sixth International Conference on Cold Fusion,Progress in New Hydrogen Energy, New Energy and Industrial Technology Development Organization, Tokyo Institute of Technology, Tokyo, Japan, Lake Toya, Hokkaido, Japan, 1996, pp. 45.
[27] P.L. Hagelstein, D. Letts, D. Cravens, Terahertz difference frequency response of PdD in two-laser experiments, J. Cond. Matter Nucl. Sci. 3 (2010) 59-76.
[28] D. Letts, D. Cravens, Laser stimulation of deuterated palladium, Infinite Energy 9 (2003) 10.
[29] E.K. Storms, Use of a very sensitive Seebeck calorimeter to study the Pons-Fleischmann and Letts effects, in: P.L. Hagelstein, S.R. Chubb (Eds), Tenth International Conference on Cold Fusion, World Scientific Publishing Co., Cambridge, MA, 2003, pp. 183-97.
[30] D. Letts, D. Cravens, P.L. Hagelstein, Thermal changes in palladium deuteride induced by laser beat frequencies, in: J. Marwan, S.B. Krivit (Eds), ACS Symposium Series 998, Low-Energy Nuclear Reactions Sourcebook, American Chemical Society, Washington, DC, 2008, pp. 337.
[31] D. Letts, P.L. Hagelstein, Simulation of optical phonons in deuterated palladium, in: D.L. Nagel, M.E. Melich (Eds), 14th International Conference on Condensed Matter Nuclear Science, Washington, DC, 2008, pp. 333-7.
[32] M.J. Guffey, Y. Tang, P.J. King, Attempted Replication of Excess Heat in the Letts Dual-laser Experiment, JCMNS 20 (2016) 1-28.
[33] J. Tian, L.H. Jin, B.J. Shen, Z.K. Weng, X. Lu, Excess heat triggering by 532 nm laser in a D/Pd gas loading system, in: D.L. Nagel, M.E. Melich (Eds), ICCF-14 International Conference on Condensed Matter Nuclear Science, www.LENR.org, Washington, DC, 2008, pp. 328-32.
[34] P.L. Hagelstein, D. Letts, Analysis of some experimental data from the two-laser experiment, J. Cond. Matter Nucl. Sci. 3 (2010) 77-92.
[35] M.R. Swartz, P.L. Hagelstein, Increased PdD anti-Stokes Peaks are Correlated with Excess Heat Mode, JCMNS 24 (2017) 130-45.
[36] M. Swartz, Active LANR Systems Emit a 327.37 MHz Maser Line, J. Cond. Mater. Nucl. Sci. 33 (2020) 81-110.
[37] E.K. Storms, Some characteristics of heat production using the "cold fusion" effect, in: T.O. Passell (Ed) Fourth International Conference on Cold Fusion, Electric Power Research Institute 3412 Hillview Ave., Palo Alto, CA 94304, Lahaina, Maui, 1993, pp. 4.
[38] A. Coehn, Nachweis Von Protonen in Metallen, Z. Elektrochem. 35 (1929) 676.
[39] F. Tanzella, R. George, R.E. Godes, Nanosecond Pulse Stimulation in the Ni–H2 System, J. Cond. Matter. Nucl. Sci. 29 (2019) 202-10.
[40] R. Godes, Quantum Fusion Hypothesis, ICCF-14, Washington, DC., 2008.
[41] F. Celani, A. Spallone, P. Tripodi, A. Nuvoli, A. Petrocchi, D. Di Gioacchino, M. Boutet, P. Marini, V. Di Stefano, High power μs pulsed electrolysis for large deuterium loading in Pd plates, Trans. Fusion Technol. 26 (1994) 127.
[42] F. Celani, A. Spallone, C. Lorenzetti, E. Purchi, S. Fiorilla, S. Cupellini, M. Nakamura, P. Cerreoni, R. Burri, P. Boccanera, Marano, G. Vassallo, G. Gamberale,

Electromagnetic Excitation of Coaxially-Coiled Constantan Wires by High-Power, High-Voltage, Microsecond Pulses, JCMNS 36 (2022) 408-35.
[43] M.R. Staker, Coupled Calorimetry and Resistivity Measurements, in Conjunction with an Emended and More Complete Phase Diagram of the Palladium–Isotopic Hydrogen System, J. Cond. Matter. Nucl. Sci. 29 (2019) 129-68.
[44] M.R. Staker, A model and simulation of lattice vibrations in a superabundant vacancy phase of palladium–deuterium, Modeling Simul. Mater. Sci. Eng. 28 (2020) 0650066.
[45] F.E. Gordon, H.J. Whitehouse, Lattice Energy Converter, JCMNS 35 (2022) 30-48.
[46] M.C. McKubre, F. Tanzella, Using resistivity to measure H/Pd and D/Pd loading: Method and significance, in: A. Takahashi, K. Ota, Y. Iwamura (Eds), Condensed Matter Nuclear Science, ICCF-12, World Scientific, Yokohama, Japan, 2005, pp. 392.
[47] E. Storms, The Present Status of Cold Fusion and its Expected Influence on Science and Technology Innovative Energy Policies 4 (2015).
[48] M.C.H. McKubre, F.L. Tanzella, P. Tripodi, D. Di Gioacchino, V. Violante, Finite element modeling of the transient colorimetric behavior of the MATRIX experimental apparatus: ^{4}He and excess of power production correlation through numerical results, in: F. Scaramuzzi (Ed) 8th International Conference on Cold Fusion, Italian Physical Society, Bologna, Italy, Lerici (La Spezia), Italy, 2000, pp. 23-7.
[49] A.B. Karabut, Y.R. Kucherov, I.B. Savvatimova, Nuclear product ratio for glow discharge in deuterium, Phys. Lett. A 170 (1992) 265-72.
[50] A.B. Karabut, E.A. Karabut, Research into spectra of X-ray emission from solid cathode medium during and after high current glow discharge operation, in: D.L. Nagel, M.E. Melich (Eds), 14th International Conference on Condensed Matter Nuclear Science, www.LENR-CANR.org, Washington DC, 2008, pp. 362-7.
[51] E.K. Storms, B. Scanlan, Detection of radiation from LENR, in: D.L. Nagel, M.E. Melich (Eds), 14th International Conference on Condensed Matter Nuclear Science, www.LENR.org, Washington, DC, 2008, pp. 263-87.
[52] S. Szpak, P.A. Mosier-Boss, J.J. Smith, On the behavior of Pd deposited in the presence of evolving deuterium, J. Electroanal. Chem. 302 (1991) 255.
[53] F.E. Gordon, H.J. Whitehouse, Lattice Energy Converter II: Iron Hydrogen Host Material, JCMNS 36 (2022) 1-24.
[54] S. Szpak, P.A. Mosier-Boss, J.J. Smith, Deuterium uptake during Pd-D codeposition, J. Electroanal. Chem. 379 (1994) 121.
[55] M. McKubre, M.R. Staker, On the role of Super Abundant Vacancies (SAV's) in hydrogen loading and production of the Fleischmann Pons Heat Effect, 13th International Workshop on Anomalies in Hydrogen Loaded Metals, Italy, 2018.
[56] M.R. Staker, Estimating volume fractions of superabundant vacancy phases and their potential roles in low energy nuclear reactions and high conductivity in the palladium – isotopic hydrogen system, Mater. Sci. and Eng. B 259 (2020) 114600.
[57] Y. Fukai, Formation of superabundant vacancies in metal hydrides at high temperatures, J. Alloys and Compounds 231 (1995) 35-40.

[58] Z.M. Geballe, M. Somayazulu, N. Armanet, A.J. Mishra, M. Ahart, R.J. Hemley, High-pressure synthesis and thermodynamic stability of PdH1±ε up to 8 GPa, Phys. Rev. B 103 (2021) 024515.
[59] M.C. McKubre, Excess power observations in electrochemical studies of the D/Pd system; the operating parameter space, in: V. Violante, F. Sarto (Eds), 15th International Conference on Condensed Matter Nuclear Science, ENEA, Italy, Rome, Italy, 2009, pp. 5-10.
[60] S. Szpak, P.A. Mosier-Boss, J. Dea, F. Gordon, Polarized D+/Pd-D_2O system: hot spots and "mini-explosions", in: P.L. Hagelstein, S.R. Chubb (Eds), Tenth International Conference on Cold Fusion, World Scientific Publishing Co., Cambridge, MA, 2003, pp. 13.
[61] V. Pines, M. Pines, A. Chait, B.M. Steinetz, L.P. Forsley, R.C. Hendricks, T.L. Benyo, G.C. Fralick, B. Baramsai, P.B. Ugorowski, M.D. Becks, R.E. Martin, N. Penney, C.E. Sandifer II, Nuclear fusion reactions in deuterated metals, Phys. Rev. C 101 (2020) 044609.
[62] T. Tanaka, S. Himeno, A possible enhancement mechanism, in: X.Z. Li (Ed) The 9th International Conference on Cold Fusion, Condensed Matter Nuclear Science, Tsinghua Univ. Press, Tsinghua Univ., Beijing, China, 2002, pp. 349.
[63] A.G. Lipson, A.S. Roussetski, A.B. Karabut, G.H. Miley, Strong enhancement of DD-reaction accompanied by X-ray generation in a pulsed low voltage high-current deuterium glow discharge with a titanuim cathode, in: P.L. Hagelstein, S.R. Chubb (Eds), Tenth International Conference on Cold Fusion, World Scientific Publishing Co., Cambridge, MA, 2003, pp. 635-56.
[64] Y.B. Gurov, S.V. Lapushkin, B. Chernyshev, V.G. Sandukovsky, Spectroscopy of superheavy hydrogen isotopes 4H and 5H, Eur. Phys. J. A24 (2005) 231-6.
[65] A. Meulenberg Jr., A. Sinha, Deep-obit-electron radiation emission in decay from $^4H^*$# to ^4He, ICCF-17, Daejeon, Korea, 2013.
[66] R.E. Godes, The quantum fusion hypothesis, Infinite Energy 14 (2008) 15-23.
[67] M.R. Staker, How to achieve the Fleischmann-Pons heat effect, J. Hydrogen Energy www.sciencedirect.com (2022).
[68] R. Mills, The grand unified theory of classical quantum mechanics, Cadmus Professional Communications, Ephrata, PA, 2006.
[69] A. Rathke, A critical analysis of the hydrino model, New J. Phys 7 (2005) 127.
[70] A. Meulenberg Jr., From the naught orbit to the ^4He excited state, J. Cond. Matter Nucl. Sci. 10 (2013) 15-29.
[71] K. Shoulders, S. Shoulders, Observations on the Role of Charge Clusters in Nuclear Cluster Reactions, J. New Energy 1 (1996) 111-21.
[72] H. Fox, S.X. Jin, Low-energy nuclear reactions and high-density charge clusters, J. New Energy 3 (1998) 56.
[73] S.-X. Jin, H. Fox, Characteristics of high-density charge clusters: A theoretical model, J. New Energy 1 (1996) 5-20.
[74] M. Rambaut, Electrons clusters and magnetic monopoles, in: J.-P. Biberian (Ed) 11th International Conference on Cold Fusion, World Scientific Co., Marseilles, France, 2004, pp. 798-805.
[75] G.K. Hubler, A Possible Heuristic Explanation of Exotic Vacuum Objects (EVO's, Charge Clusters), JCMNS 36 (2022) 30-7.

[76] E. Lewis, The ball lightning state In cold fusion, in: P.L. Hagelstein, S.R. Chubb (Eds), Tenth International Conference on Cold Fusion, World Scientific Publishing Co., Cambridge, MA, 2003, pp. 973-81.
[77] E.H. Lewis, Evidence of microscopic ball lightning in cold fusion experiments, in: J.-P. Biberian (Ed) 11th International Conference on Cold Fusion, World Scientific Co., Marseilles, France, 2004, pp. 304.
[78] E.H. Lewis, Evidence of ball lightning -- A survey of some recent experimental papers describing microscopic objects associated with transmutation phenomena, in: J. Rothwell (Ed) ICCF-14 International Conference on Condensed Matter Nuclear Science, www.LENR.org, Washington, DC, 2008.
[79] E.H. Lewis, Tracks of ball lightning in apparatus?, J. Cond. Matter Nucl. Sci. 2 (2009) 13.
[80] A.I. Goncharov, V.A. Kirkinskii, Research Article Formation of Hydrogen Miniatoms in the Medium of Free Electrons–the Key to the Mechanism of Low-energy Nuclear Reactions, JCMNS 36 (2022) 203-9.