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A New Understanding of Cold Fusion

Edmund Storms
Kiva Labs, Santa Fe, NM
storms2@ix.netcom.com

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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 nuclear process results from an unusual chemical condition in which a structure forms that can cause nuclear fusion when isotopes of hydrogen are present. 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 as a guide for 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. When applied, this process would be 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.

Many scientists found good reasons to reject their claims. As everyone knows, such a fusion reaction is 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, when it occurs the behavior is obvious and unambiguous. 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 any plausible chemical reaction.

A skeptic might reasonably reject a single measurement or a collection of measurements after the 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 have been produced in various materials using a variety of treatments. Because nuclear reactions besides fusion 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 when PdD and other similar compounds are exposed to deuterium, which is here identified as "cold fusion". In addition, because this paper is not a review, only a few examples of the reported behavior are cited to give the reader access to a source of important details.

Before discussing the F-P claims, the reader needs to understand that two different mechanisms can be used to cause fusion in a material. The mechanism discovered by F-P occurs without the application of energy, hence is called cold fusion. The other mechanism requires the application of significant extra energy, usually in the form of kinetic energy applied to one of the D+ ions, hence is called hot fusion. Because these two mechanisms cause the production of different nuclear products at significantly different rates, they cannot be understood to involve the same process. Only the cold fusion process is described here.

Copies of the ICCF conference papers, the 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 best 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 need to be understood.

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. In other words, cold fusion is first a chemical process that can cause a nuclear process as a result of the chance behavior of an unusual relationship between the electrons and the nuclei. Thus, we are required to first understand the chemical process.

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. A different array cannot form within this structure because this arrangement of electrons and nuclei has the lowest energy of any other. Therefore, for the deuterium nuclei to achieve a condition required for fusion, the process has to function outside of the lattice

structure where the chemical environment is different. Consequently, the prefusion structure cannot form within vacancies in the lattice structure. Otherwise, these vacancies would no longer be vacancies and the structure would no longer be fcc if these sites were occupied by atoms, other than by an occasional transient. 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 with the required loss of Gibbs energy. This issue is discussed in greater detail in Section 4.2.3.

The fusion process has to be an unexpected consequence of this chemical process because the possibility of a nuclear reaction cannot be anticipated by a chemical system any more than TNT can form with the anticipation of it being an explosive. Chemical reactions respond only to local conditions and not to what might be possible in the future. Consequently, we need to start our understanding by examining the conditions that can be created in a material by a normal chemical process, with the nuclear reaction being a novel and unexpected consequence.

Because the fusion process requires the formation of unique sites located outside of the normal lattice structure and because these sites are rarely formed, the total number of such sites and how often each can result in fusion would determine the amount of power, not the rate of the nuclear reaction itself. Although the fusion reaction would require some time, its rate would be far faster than the assembly process, both initially and as D are replaced after being converted to a different element by the fusion process.

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 the Coulomb barrier to be altered to allow 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, an explanation must focus on electron screening. 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 operates to produce the observed reaction rate. The challenge is to explain how this new process might work because the mechanism is not the same as the one operating during hot fusion. This difference is explained 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, which has not been detected. 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 discovered. Also, many methods are now known to initiate the process, not just electrolysis as was used initially to react Pd with D.[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 error or by a prosaic process limited to a particular environment 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.

A few of the many proposed models have been described and evaluated by the author in a 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, the author suggests the predictions be tested to determine what is real and what is only imaginary, as is normally required in conventional science.

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? Because this paper is not a review, all of the published information will not be evaluated. Instead, 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. The implications of these behaviors are discussed in a later section. But first, each important behavior is discussed.

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 prosaicß 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 under certain conditions. 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.

Figure 1[15] shows a small example of successful efforts to make energy when compared to the amount of power produced. Notice that the number of reported values decreases as the amount of measured power increases. Even though this figure compares only a very small fraction of the total number of successful reports now available, the behavior reveals important information about the nature of the mechanism.

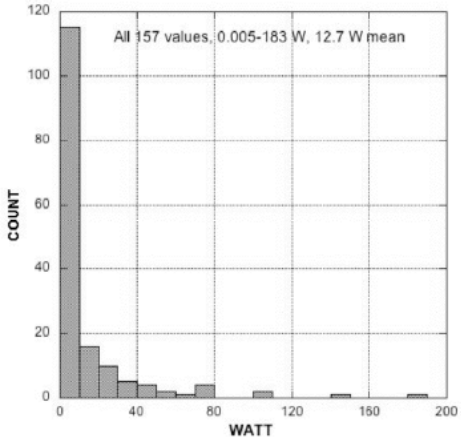

FIGURE 1. *Histogram showing the number of reported values for the measured power produced by similar samples containing PdD. Values are taken from Table 2, "The Science of Low Energy Nuclear Reaction"[5] published in 2007.*

The shape of the histogram suggests a probability function could be used to describe the ability to produce the conditions required to support the fusion process. Said another way, the shape suggests 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 frequently 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 condition, thereby increasing the amount of nuclear power. Effective methods have been gradually discovered and applied, as I have summarized.[7]

3.2 Effect of temperature,

The effect of temperature is important because the low temperatures known to cause LENR cannot directly affect 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 observed that power could be increased by increasing the temperature.[16, 17] They called this the "positive feedback effect", which, unfortunately, distracted from how the temperature actually affects the process. Over the years, other people[18] measured at various temperatures and found that, indeed, the amount of power increases with temperature. Storms[19], using a very accurate calorimeter, measured over a wide range of temperatures and found that the temperature has the same effect when the measurement is made in the electrolytic cell or D_2 gas, as shown in Fig. 2. Other measurements by Storms and other people[18] show that this temperature effect continues at temperatures at least as high as 500° C.

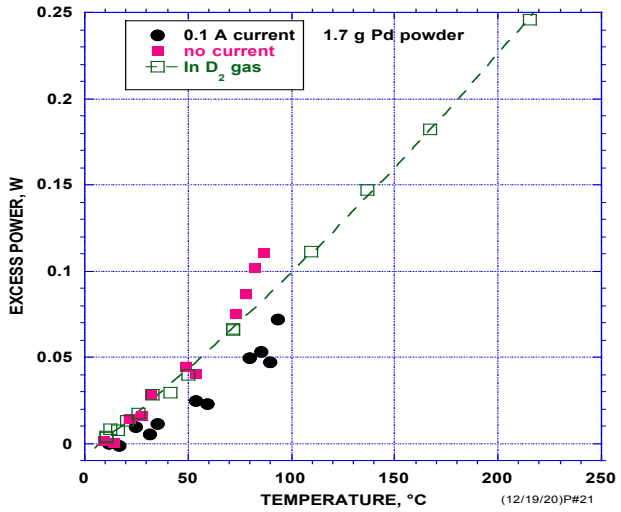

FIGURE 2. *Excess power is a function of temperature when a sample of PdD is heated in the electrolytic cell or when it is heated in D_2 gas. Production of power at the higher temperatures continued even after the current to the sample is stopped in the electrolytic cell. No detectable power was found 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 amount of power. This value represents the amount of energy required to overcome an energy barrier. 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 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] 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, which is consistent with the data

shown in Fig. 2 when the electrolytic current was stopped to allow D to leave the Pd cathode.

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] Temperature and/or the surrounding D activity, including the gas pressure, can be used to modify the flux.

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 past measurements at room temperature would suggest.

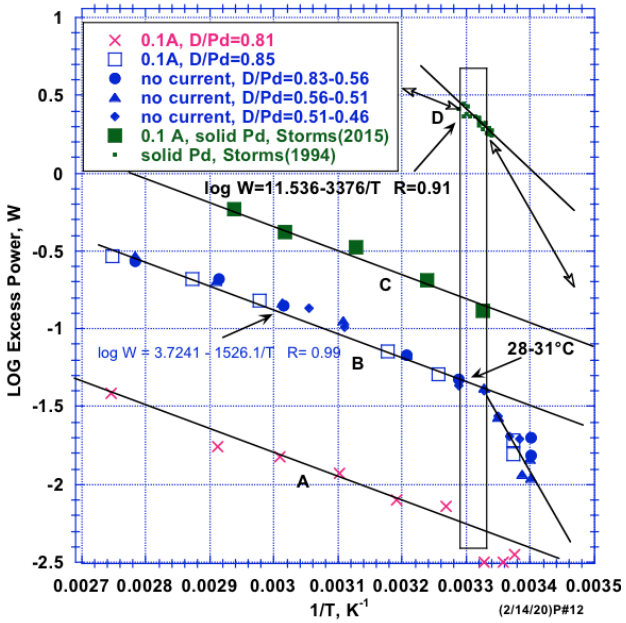

FIGURE 3. *Comparison between the behaviors of different samples of solid and pressed powdered Pd when heated in an electrolytic cell. The designations A, B, C, and D apply to independent measurements. The lines drawn through each measurement are parallel, showing that each has the same activation energy.[19, 22]. The study labeled "D" fell in the transition temperature region between two different values for the activation energy. 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 cause the power to increase, as reported by McKubre et al. [25] (Fig. 4) and 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.

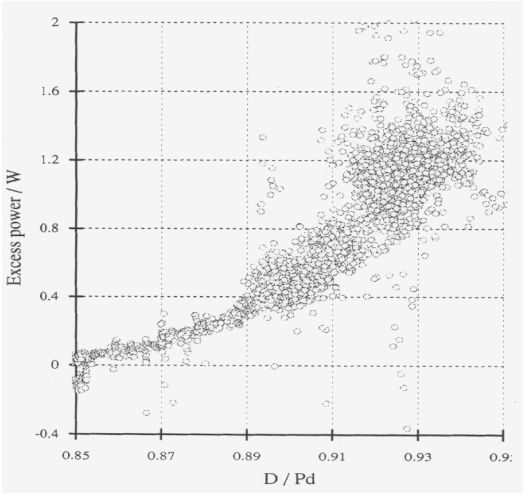

FIGURE 4*. Effect of D/Pd ratio on power production when an active batch of Pd wire was reacted in an electrolytic cell near 20° C. McKubre et al. [25]*

3.4 Effect of the laser

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] as support for 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 special 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.

Clearly, the laser can stimulate the nuclear process but why this happens is still unknown.

3.5 Effect of Applied Current

Increased current applied to the electrolytic cell is known to increase the amount of power[5, 37], presumably because it increases the availability of D to the fusion reaction while also increasing the temperature. However, studies using the direct reaction between PdD and D_2 gas reveal that when a current is caused to pass through the PdD

structure more power would result. This behavior was explained as being caused by electromigration 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 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.

Encouraged by these studies and the model described here, I applied a steady DC to solid PdD heated in D_2 gas. 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, the temperature was changed by heating the cell by using a surrounding resistance wire.

It's important to note that the effect of applied current is large, it 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.

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)*

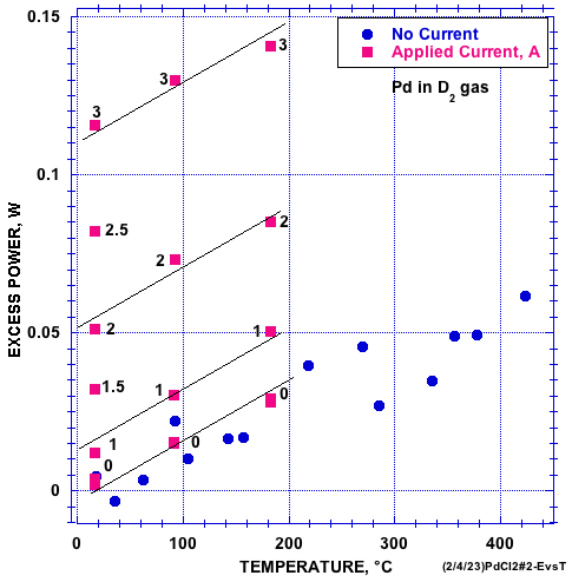

FIGURE 6. *Effect of a steady DC passing through PdD at various temperatures in D_2 gas. The amount of applied current is shown in units of ampere(A). The values for "no current" were obtained first followed by the values designated as "applied current".*

3.6 Helium production

Helium was expected and 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. This creates a problem because the nuclear reaction has no obvious way to conserve momentum when the nuclear energy is dissipated. Why the energy released by fusion is not sufficient to destabilize the He nucleus, as it does when hot fusion occurs, is an important question that is discussed in a later section.

The fusion of two D results in 2.6×10^{11} He/watt-sec.[10, 15, 43] When the amount of measured energy is compared to the amount of measured helium and plotted as the He/watt-sec ratio, Figure 7 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. Even so, 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.

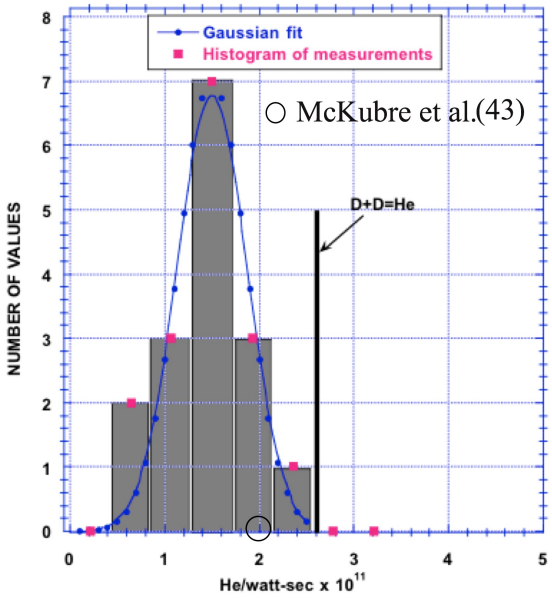

FIGURE 7. *Histogram of 16 measurements by four independent studies showing the amount of helium divided by the amount of energy produced by electrochemical cells containing D_2O. A Gaussian error function is fit to the distribution of values. The ratio based on the mass change for the fusion reaction $D+D=^4He$ is shown.[43] 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 7, McKubre et al.[44] 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 exceeded the concentration in the air. The resulting relationship between energy and helium is shown in Fig. 8 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) of $2.0\pm0.8\text{x}10^{11}$ is compared to the values shown in Fig. 7. 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 the sample could be flushed out under a vacuum by repeatedly reacting the sample with D_2.

In summary, the He/energy ratios produced during electrolysis near 20° C are consistent with an error function typical of independent measurements. 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.

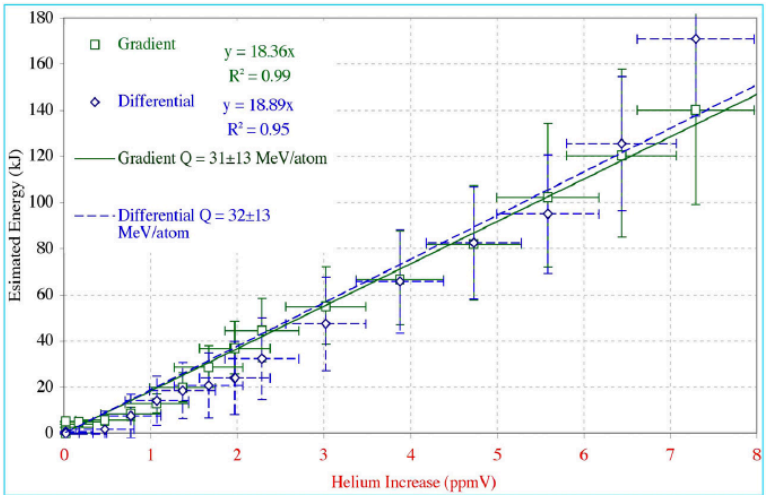

FIGURE 8. *Energy and helium were made by a special batch of coconut charcoal to which 5% Pd was applied as fine particles and heated near 243°C in D_2 gas while energy and helium were measured as reported by McKubre et al.*

3.7 Tritium production

Tritium is a minor nuclear product that is detected 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. 9. 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.

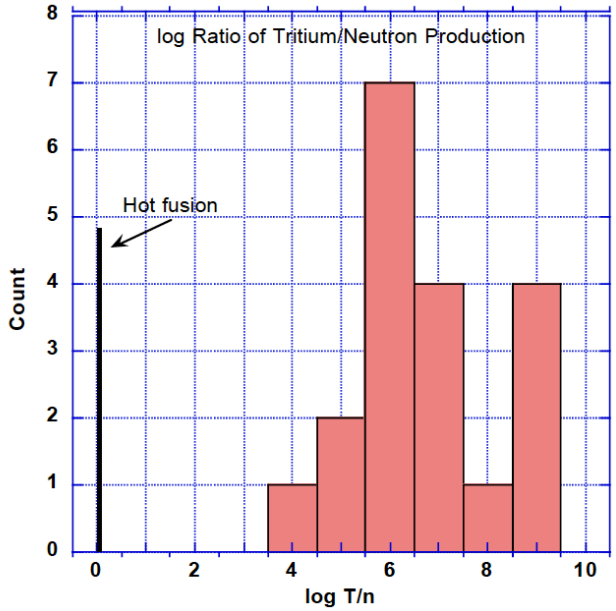

FIGURE 9. *Histogram of published measurements of the log tritium/neutron ratio. The measured log T/n resulting from hot fusion is also plotted. The values are from Table 6, "The Science of Low Energy Nuclear Reaction".[5]*

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.

3.9 Ion emission

People naturally assumed the observed helium gas (Fig. 6) was emitted with most of the nuclear energy, in the manner of normal alpha emission. Karabut et al.[45] 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[46] measured photon radiation having laser-like behavior (Fig. 13) with energy suggesting the emission of both gamma-rays and X-rays. Some of this radiation 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. 7 and 9. Nevertheless, the behavior is not typical of a "normal" nuclear process.

Eight years later, Storms and Scanlan[47] also measured the ion spectrum (Fig. 10) 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 an 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.

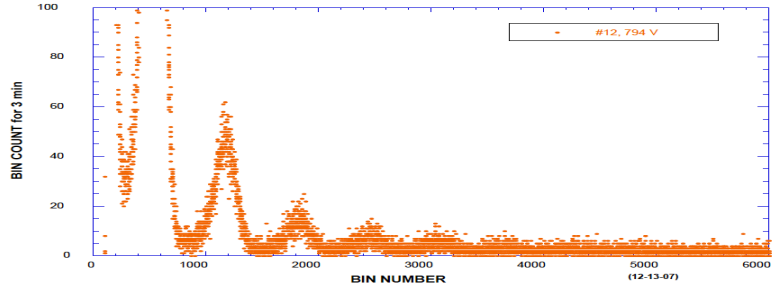

FIGURE 10. *A typical spectrum is produced during gas discharge when either H_2 or D_2 is used. The bin number was calibrated using the energetic alpha emitted from Po^{210}.*

Confidence in this measurement and the one reported by Karabut et al.[45] 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. 11.
2. The number of ions in each peak decreased as the amount of energy increased, as shown in Fig. 12.
3. The spectrum is unchanged by the use of either H_2 or D_2.
4. The energy change that occurred 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 from a fusion reaction is contained in this radiation.

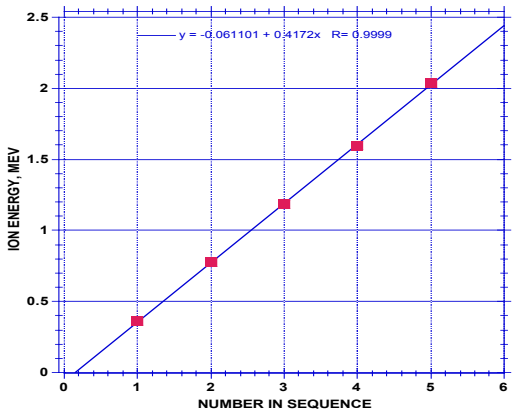

FIGURE 11. *The relationship between the sequence in the spectrum and the ion energy when the first peak is given a value of 1.*

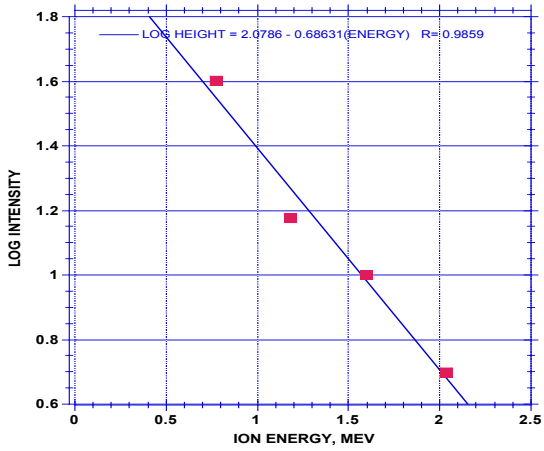

FIGURE 12. *The relationship between log intensity and ion energy. The intensity is given as a relative value.*

`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. 11), 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. An explanation is suggested in the next section.

When the relative intensity is plotted as a function of energy (Fig. 12), 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 that 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, a single nuclear product prevents the conservation of 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. None of the published theories presently account for this behavior.

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. 13. Apparently, photons having a wide range in energy are emitted as tightly focused beams in random directions with different intensities. Szpak et al.[48] 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.

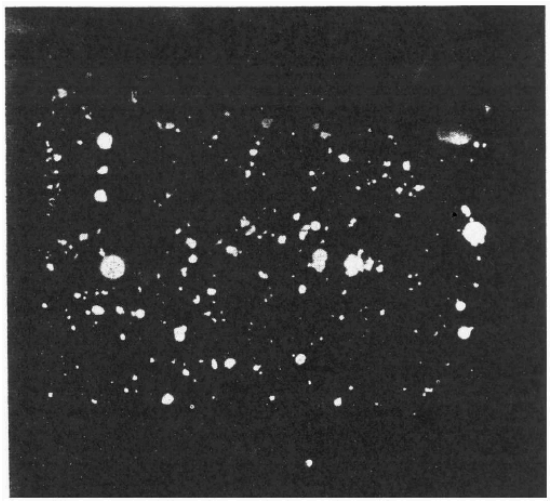

FIGURE 13. *Spots are produced on photographic film by photons that passed through 0.5 mm of aluminum. A similar pattern is produced when 2 mm of Pb is used.*

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)[49] measured a strong electron current being emitted from a deposit of Pd exposed to D_2 and from a deposit of Fe[50] 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[51], in the

manner used by G-W. This material was placed in D_2 gas with another electrode made of Pt, which was used to collect the electron emission. This collector-sample assembly is shown in Figure 14. 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.

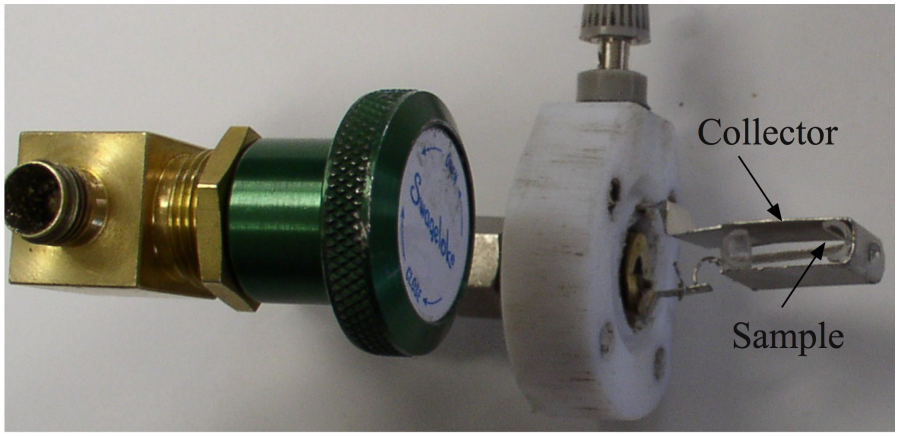

FIGURE 14. *Photograph of the sample-collector assembly.*

The material was heated in D_2 gas over a temperature range, as shown in Fig. 15. Excess power and electron current are both increased by increased temperature. This suggests both have a causal relationship with each other.

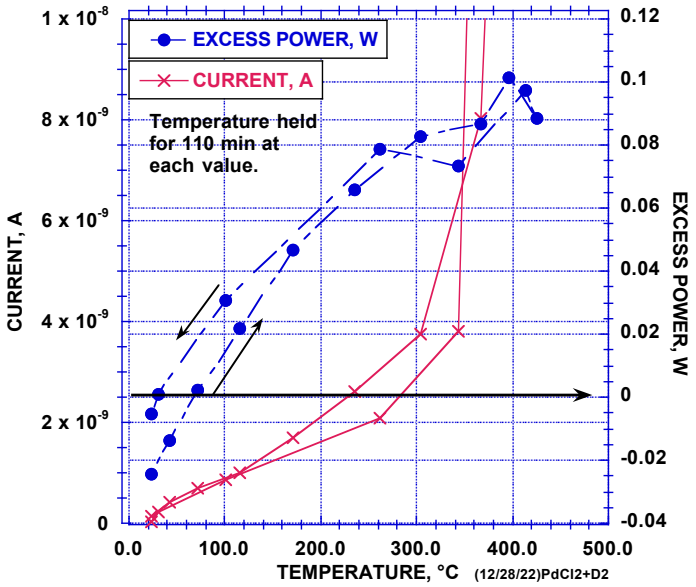

FIGURE 15. *Excess power and emitted electron current are measured as a function of temperature when co-deposited Pd is heated in D_2 gas. The electron emitter is held at 0 V relative to the collector. The arrows indicate the sequence of the measurements. The excess power was measured before the current was measured. The current was then measured when the temperature was increased and then decreased. The temperature is measured inside the cell but not in the sample.*

Electrons can escape from the sample only when the fusion reaction takes place very near its surface while heat energy is measured regardless of where it is produced. As a result, two different chemical environments and perhaps different temperatures would influence these behaviors in different ways. In addition, some current could result when ions are created in the D_2 gas, either by the emitted electrons or various chemical reactions. Such current is proposed to result from these additional sources when the temperature is increased above 350° C. The current measured at temperatures below 350° C is proposed to result from only the nuclear process.

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 held at 298° C, with the sample having a negative potential relative to the collector. This potential would encourage all emitted electrons regardless of their energy to leave the surface and be collected as a current. Any ions in the gas would add to this current. The lack of a change in current as the voltage is decreased and approaches zero indicates that gas ionization is not a source of significant current because the ion current would decrease as the voltage approached zero. This decrease is not seen. 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. 16) 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 at only a few volts. As a result, we once again have a question to answer.

Figure 17 shows how the current changes with time as the voltage increases. After each voltage is applied, the current changes at a rate that decreases as the voltage increases, 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. Perhaps the emitted current that is caused to return to the surface stimulates an increase in the production of current. 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 event. 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.

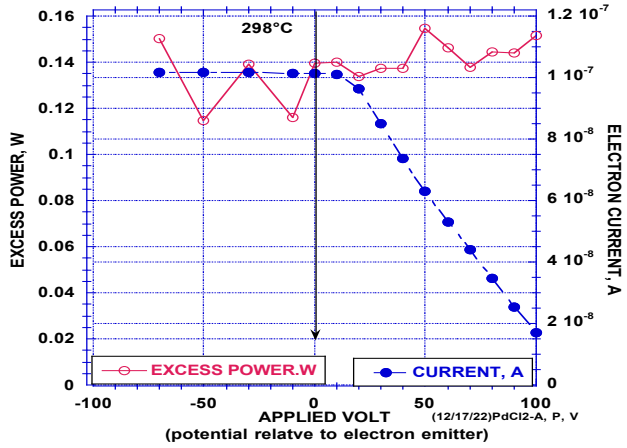

FIGURE 16. *Electron current and the excess power at a temperature of 298° C when the voltage between the emitter and collector is changed. The potential is shown relative to the emitter.*

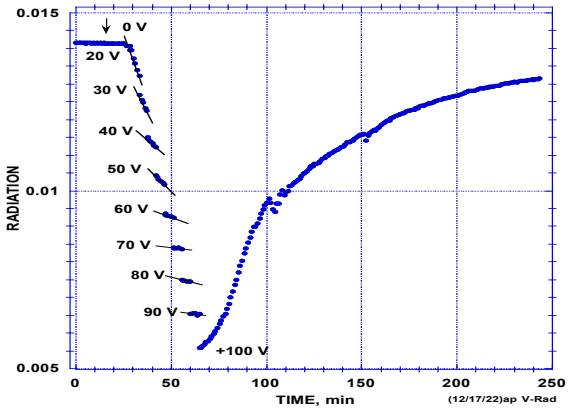

FIGURE 17*. Effect of time on the voltage measured across a series resistor when the voltage across the cell is changed as shown in Fig. 16.*

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.

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 chemical reactions followed by nuclear reactions. Each needs to be understood as an isolated mechanism as well as their relationship with each other.

The presence of H or a mixture of D+H will cause different nuclear products that result from the same mechanism as operating during D+D fusion(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 apparently so difficult for people to accept who do not understand the nature of chemical interaction, that I hope I can be forgiven for repeating the reasons so many different ways. In fact, if the NAE were actually in the vacancy structure, this source of energy could not be made to occur at the rates required to make commercial power because the number of active sites would be too small. Other considerations also apply as elaborated below.

The tetrahedral site fails because each of these sites has the same chemical properties, 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[52-54] that vacancy tubes are present in PdD as the NAE is very weak because the claim by Fukai[55] on which this idea is based could not be replicated.[56] 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, 57] 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. [58]. 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 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 path 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 the nuclei, usually in 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 screening to increase the very small rate of the hot fusion reaction, especially at low kinetic energy, as shown in Fig. 18.[59, 60] 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.

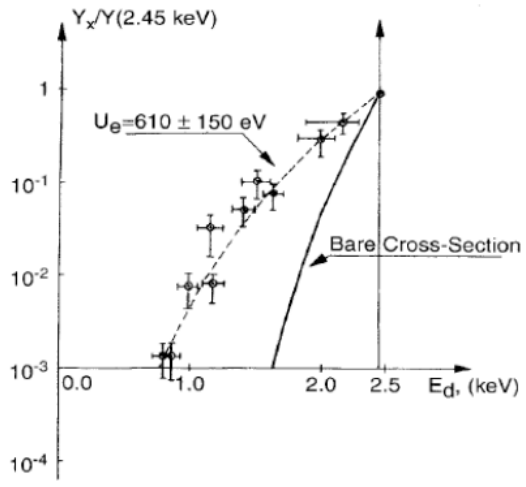

FIGURE 18. *D+ bombardment of Ti with kinetic energy to produce the plotted rate of hot fusion relative to when a kinetic energy of 2.45 KeV [61] is applied. A calculated value for the screening potential (U_e) is shown. The bare cross-section is obtained when fusion occurs in plasma. The absolute fusion rate at this energy is near the detection limit, to which electron screening adds very little to the very small fusion rate.*

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 and the resulting helium nucleus does not fragment.

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. 7, ^{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.[62] In fact, the decay is so rapid, some doubt has been expressed 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. 10. In addition, Meulenberg and Sinha[63] (M+S) suggest that based on theory, ^{4}H can 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[64] has 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 needed to form a neutron 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 converts 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

The use of only H would result in an increasing amount of tritium (^{3}H) as the 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 was 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 then does the use of Ni appear to be required to make significant energy when only H is used? I speculate that the tritium is more effectively retained in the NAE of Ni compared to Pd. 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 T/n values (Figure 9) would be caused by random variations in the D and T concentrations during the various studies. A careful study of the T/n ratio while the concentrations of T and D are measured 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 missing energy? The proposed answer is that the assembled electrons, which would interact with the nuclear energy states as fusion occurred, would acquire some of the resulting nuclear energy and dissipate it with momentum as an emitted 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 site. The availability of the nuclei is determined mainly by temperature and access to the source of D+ ions, as has been described previously[20]. We now turn to the effect of electron availability.

Electrons in a metallic conductor, such as PdD, have two different levels 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 reaching a 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 both Godes[39] and Celani et al.[42] who have applied a current to successfully increase the rate of power production, but 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 a 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 emission.
5. An electron current when passed through the NAE will increase the fusion rate.
6. A flux of hydrogen isotopes passed 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 present in a large number of emitted electrons, each of which has only a small fraction of the total and has 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. The first step toward this understanding has now been taken during the last 32 years. 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 the nuclear mechanism 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.

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.

Let's now go deeper into the rabbit hole. Suppose the electrons gradually assemble, thereby causing the D nuclei to interact. As yet, we do not need to know why they assemble. We only need to explore the logical consequences of the assembly process.

As more electrons are added to the assembly, the nuclear energy states of the D nuclei would interact to a greater extent with the electron cloud. Mills[65] provided a partial description of this process in the form of the hydrino. Rathke[66] and Meulenberg[67] 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 behavior of cold fusion (Fig. 16) suggests that many electrons, rather than only a few, can interact with the nuclear energy states of the hydrogen nuclei.

Based on the mathematical functions used to describe energy, the assembly could be viewed as a large nucleus containing electrons in energy states normally not present in a nucleus. Those electrons that could interact with the nuclear energy states would be then able to dissipate a small part of the mass-energy when they were emitted from the assembly. This emission would accelerate as the electron assembly became increasingly unstable as the combined energy states began to approach those of helium. 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 be able to fragment. Instead, the extra energy would be dissipated by beta emission. During this process, the assembly would act like a new kind of matter having a large negative charge and unusual magnetic properties. Has a suitable structure been suggested and observed?

As described by Shoulders[68], the structure he discovered would have the required characteristics, except it did not experience fusion when he made it; perhaps because it did not contain a hydrogen isotope. He called this an EVO. Fox[69] and Jin[70] explored the idea in greater detail. Rambaut[71] describes this electron structure as a magnetic monopole. Hubler[72] provides a different explanation for the same behavior. Ball lightning has a similar characteristic but on a larger scale.[73-76] Because

this structure, in its several forms, has been made and studied using electric discharge, its ability to form in a chemical environment must be assumed.

In contrast to this relatively "slow" dissipation process, the assembly could "explode" after enough electrons have slowly assembled to cause a nuclear interaction, thereby causing all of the electrons and the fusion product to be scattered in certain directions while momentum is conserved. Once again, each electron would carry only a small fraction of the total nuclear energy.

The challenge is to determine which of these mechanisms occurs because both are consistent with present observations. Regardless of which of these mechanisms apply, hot fusion can be said to represent fast fusion and cold fusion can be described as slow fusion. 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. These exceptions result because when the process converts one hydrogen isotope into another, these two isotopes happen to be radioactive.

Nevertheless, the final nuclear product is found to contain some kinetic energy, the value of which is shown in Fig. 10. Why this energy has values that have a fixed difference is still unknown and needs to be explained.

Although the energy loss is gradual, it would be fast by human standards and limited by how fast electrons could be returned to the fusion site from the surrounding conduction band to replace the steady loss by the first mechanism or how fast the D or H could be replaced after the "explosion" if the second mechanism were operating. The resulting nuclear process might have a half-life that determines the rate at which the nuclear events occur.

After the ^{4}H had formed, it would decay by the normal emission of a very energetic electron (beta decay) with a short half-life. The predicted presence of this energetic electron needs to be sought. Of course, some of the energy would be lost to neutrino emission.

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 as the result of many different treatments and in many different kinds of materials. This structure is proposed to consist of two 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 nuclear interaction.

To cause fusion, this structure must allow at least two D to get close enough for their nuclear energy states to interact. The electrons that cause this reduction in separation 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. Briefly stated the electron structure that allows fusion to happen provides the means for the nuclear energy to be dissipated while momentum is

conserved. Whether this emission of electrons is a sustained or sudden process has yet to be determined.

This kind of electron structure might form in many materials but be ignored because nothing unusual happens. The sites would be made visible 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. A description based on a similar assembly of atoms and electrons has been suggested by Goncharov and Kirkinskii[77]

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.

Fusion of deuterium nuclei would create 23.8 Mev/event. The release of this energy would send all of the components, including the electrons, in different directions. This process allows the momentum to be conserved. So, instead of the energy being released from the nuclear product, as is the case when hot fusion occurs, the energy and momentum are released from the entire assembly of components that are involved in lowering the Coulomb barrier. This process represents a new kind of nuclear interaction that can only take place within a chemical environment. While this idea may be considered implausible, the explanation is consistent with many observations. In addition, the predicted behavior can be used to test the consistency of the model.

Cold fusion is not just a clean source of energy. It also reveals the existence of a new kind of atom-electron interaction on par with the interaction that causes crystals to form. However, this structure can cause a nuclear reaction when hydrogen isotopes are present. Consequently, this event makes the structure visible enough for people to take notice. The implications of such a structure being possible are huge. This is on par with the discovery of radioactivity in 1896. This discovery required all the understanding of nuclear behavior accepted at that time to be rewritten. We are now at a similar time of transition in scientific understanding.

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 properly stimulated. 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 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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