# A New Understanding of Cold Fusion

Edmund Storms
Kiva Labs, Santa Fe, NM
storms2@ix.netcom.com
ORCID 0009-0004-7675-4279

Keywords: cold fusion, LENR, CMNS, clean energy, theory, gap, nuclear mechanism

**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 information also includes new experimental results from studies involving electron emission and the effect of applied electron current.
The nuclear process results from an unusual chemical condition in which a physical structure forms in which many electrons and a few hydrogen nuclei can assemble. Nuclear fusion can occur within this assembly. The process is proposed to take place outside of the lattice structure in physical gaps having a critical dimension. The fusion process has two significant consequences. It promises to be a source of clean, inexhaustible, and inexpensive energy. In addition, a new kind of nuclear process involving the assembly of many electrons in an unusual structure is revealed. Although the proposed mechanism cannot yet be described in mathematical detail, its major features can be identified and used as a model 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 present in ordinary palladium metal when it was reacted with $D_2O$ in an electrolyte cell at room temperature. Because this discovery might provide a safe, pollution-free, and inexpensive source of energy having a great benefit to society, the announcement created much interest worldwide. Unfortunately, this interest became short-lived as a myth was created claiming the observed behavior was based on faulty measurements.

Consequently, this paper attempts to answer three questions. First, is cold fusion real? Second, what do the behaviors imply about the reaction process? And third, can a logically consistent mechanism be found to explain the observed behavior without violating the Laws of Science? The answers suggest a new kind of electron interaction is possible.

Based on conventional understanding, such a fusion reaction is considered impossible because the energy required to overcome the Coulomb barrier is absent, and the nuclei in an 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 created a myth that lives even today. Huizenga[3] gives the scientific reasons for the rejection and

Krivit[4] describes how the rejection was accomplished. This myth is no longer valid for the following reasons.

Although the nuclear process is a challenge to produce for reasons now understood, the behavior is often 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 several different reactions. The resulting nuclear products, including tritium ($^{3}H$) and helium ($^{4}He$), have been identified by many independent studies.[5] Heat energy is the main nuclear product, with the amount measured being many orders of magnitude greater than can be accounted for by any plausible chemical reaction. This heat energy is also consistent with the amount of $^{4}He$ generated by the fusion process, as is shown later in this paper.

A skeptic might reasonably reject a single measurement or a collection of measurements after a common error has been identified, but a collection of consistent 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 and applied to produce useful power.

An explanation is made more complex because many additional nuclear reactions, besides fusion, have been produced in various materials using a variety of treatments. This unexpected behavior encouraged a change in the original name of cold fusion to "low energy nuclear reaction" (LENR) or sometimes "condensed matter nuclear science" (CMNS). These additional reactions demonstrate the operation of a very complex mechanism having even more conflict with conventional understanding. Nevertheless, this paper focuses only on the claims made by F-P that involve the production of significant energy and nuclear products as the result of fusion when PdD and other similar compounds containing isotopes of hydrogen are subjected to special treatment. Because this paper is not a review, only a few examples of the extensively reported behavior are cited. Additional information is available in the cited papers. Copies of the cited ICCF conference papers, papers published in JCMNS, and many other papers can be found at www.LENR-CANR.org. Also, rather than evaluating the many conflicts between the proposed theories, these conflicts are explored by asking questions to which answers are obtained from experimental observations, not from theory. The answers are used to support a new explanation based only on the observed behavior. Logical implications are also explored. Even though an effort is made to reduce the number of miracles, the explanation is complex and requires unconventional ideas. So, a careful reading of the entire paper is suggested before a judgment is attempted.

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[2, 6], usually in the form of kinetic energy applied either in plasma, by using laser energy, or during ion bombardment. Hence this mechanism is called hot fusion. Because these two methods

produce different nuclear products at significantly different rates, they are not expected to involve the same mechanism. Only the cold fusion mechanism is described here.

For those readers who like to know the ending before they read the plot, the final consequences of this analysis are summarized in the attached Appendix I.

## 2.0 OVERALL BEHAVIOR

The process can be viewed as the consequence of four stages, with each acting in sequence as a separate event. The first two stages involve the rules normally applied to chemical behavior because the events occur in a chemical environment. The last two stages involve rules that apply to a nuclear process. An effective understanding can only be achieved by having this sequence be a part of the explanation. These stages are discussed in more detail in Section 4. But first, the general features of each stage need to be understood because this process is unlike any conventional chemical or nuclear behavior. Seeing where the logic is headed in advance hopefully will make the path easier to follow before all of the questions are answered in detail in later sections.

### 2.1 Chemical issues

We start with the obvious fact that for cold fusion to occur, two nuclei must occupy the same location at the same time. The D nuclei in a chemical system are too widely separated to allow nuclear interaction at their normal locations because 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. Furthermore, the chemical process involving the assembly of nuclei and electrons would not anticipate a nuclear reaction being the result. Consequently, the process would have to follow the Laws of Thermodynamics, as do all chemical reactions, with the nuclear reaction being an unanticipated event.

Next, we need to determine the nature of the unique local condition in which the fusion process occurs because it does not happen everywhere in the material. 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 Gibbs energy of any possible configuration. A good description of the fcc structure is found at https://en.wikipedia.org/wiki/Cubic_crystal_system.

Cold fusion requires the formation of a different arrangement. For this to happen, we are encouraged to look where the chemical environment is not controlled by the rules governing a crystallographic arrangement. If the atoms required for fusion to occur were to occupy these sites, the structure would no longer be fcc. Furthermore, because these sites are all chemically identical, if one could be occupied all would be occupied. These very basic considerations eliminate vacancies in the lattice structure as the site of the fusion process.

In addition, for the atom arrangement supporting fusion to form, the D must be more chemically stable in the new arrangement compared to where it is normally 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. This issue is discussed in greater detail in Section 4.2. 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 a unique chemical condition and because these sites are rarely formed, the total number of such sites and how often the required structure could form at each site 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 after being converted to a different element. Because the chemical process would be expected to control the observed amount of power, an effort to make useful energy needs to focus on this aspect of the 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 a reduction in the Coulomb barrier so that the nuclei can get close enough for the required energy sharing to take place. Two processes can be used to achieve this goal. These involve the application of kinetic energy and/or electron screening. Because too little energy is normally available when cold fusion occurs to cause brute force interaction, the explanation must focus on electron screening. A different mechanism, called tunneling, also can be applied to account for the apparent reduction in the Coulomb barrier. Both ideas explain how nuclear interaction can take 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 amount of screening required to cause the rate at which cold fusion occurs.[7] The challenge is to explain how this greater screening process might work. Suggestions are explored later in the paper.

After fusion has occurred, the resulting nuclear energy must be dissipated while momentum is conserved. This process 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 solution to this problem is suggested in Section 3.8.3 and the consequences are explored in Section 4.3.

The nuclear process can take place in many materials, not just in PdD as was used initially. Also, many methods besides electrolysis are now known to initiate the process.[8] Furthermore, both deuterium (D) and ordinary hydrogen (H) will produce similar amounts of nuclear power when suitable materials are used. These behaviors demonstrate the existence of a universal behavior that is not caused by a particular environment, by a single hydrogen isotope, or by a unique treatment. We are encouraged to search for this universal condition in which the same mechanism can operate.

Finally, the released nuclear energy has to be dissipated, but without producing energetic radiation, which is not detected outside of the apparatus. Some neutron emission is occasionally detected but this seems to be produced by secondary reactions. Nevertheless, some radiation and several nuclear products are detected[9, 10] 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 3.8.

I evaluated a few of the many proposed models in my book.[11] This paper will not repeat this critique. Instead, another explanation is added here 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 exploring the 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. This approach is required before a mathematical explanation can be applied with confidence.

In summary, cold fusion appears to involve a series of chemical processes that unexpectedly 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 were not made obvious by a nuclear event.

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

## 3.0 DISCUSSION

Two questions are answered first 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, albeit while involving a very unusual nuclear process

### *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. In every case, the suggested errors were either eliminated in future studies or shown not to be important. 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. All isotopes of hydrogen appear to fuse although deuterium has been given the most attention. The deuterium concentration 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, is subjected to low-energy plasma generated in a gas or liquid, subjected to cavitations by the application of sonic or mechanical energy, 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 and which isotope of hydrogen is used. The critical variable involves the formation of the active sites.

Figure 1[12] 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 PdD 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 made 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. As of 2023, over 500 papers have reported excess energy production from many different samples during which a similar behavior is produced.

The shape of the histogram in Fig. 1 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 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 many unique sites will form in a particular sample. The challenge is to increase the probability of forming the required sites, thereby increasing the amount of nuclear power. We can be encouraged by there being a few samples from which a significant amount of power is produced. This random success suggests effective methods are available to increase the power, as are being gradually discovered and applied.[8]

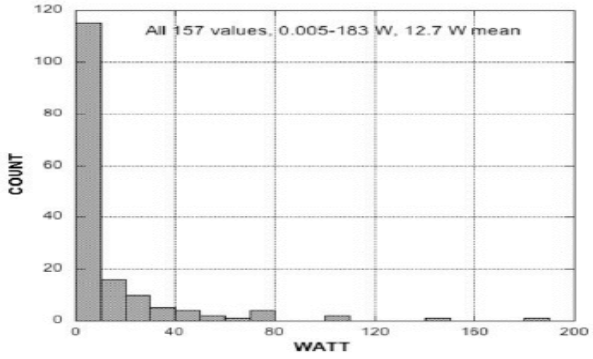


***FIGURE 1.*** *Histogram showing the number of reported values for the measured power at room temperature produced by similar samples containing PdD and exposed to electrolysis. Values are taken from Table 2, "The Science of Low Energy Nuclear Reaction"[5] published in 2007.*

**3.2 Effect of temperature**

The temperatures used to affect energy production are too small to 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. The search also reveals that the D/Pd ratio does not affect the ability to make energy after the nuclear process starts.

Most early studies were made at temperatures near 20°C even though F-P[13, 14] 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[15] 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[16] made measurements over a wide range of temperatures and found the same effect when the measurement is made in either the electrolytic cell or in $D_2$ gas, as shown in Fig. 2. In addition, as can be seen when the current in the electrolytic cell is turned off, thereby causing a loss of D from the sample, the effect of temperature is not changed by a change in the resulting D/Pd ratio.

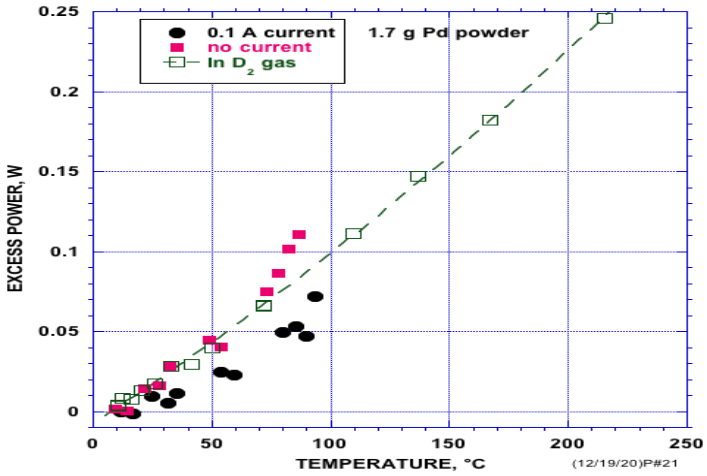


***FIGURE 2***. *Excess power is a function of temperature when a sample of PdD is heated in the electrolytic cell or when it is heated in $D_2$ gas. Production of power at the higher temperatures continued even after the current to the sample was stopped in the electrolytic cell. No detectable power 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,[16] 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 the diffusion of D controls power production under certain conditions.[16, 17] However, when the reaction with $D_2$ gas 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 is

also shown previously in Fig. 2. Here, once again, the amount of power remained unchanged after the electrolytic current was stopped.

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.[18].

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

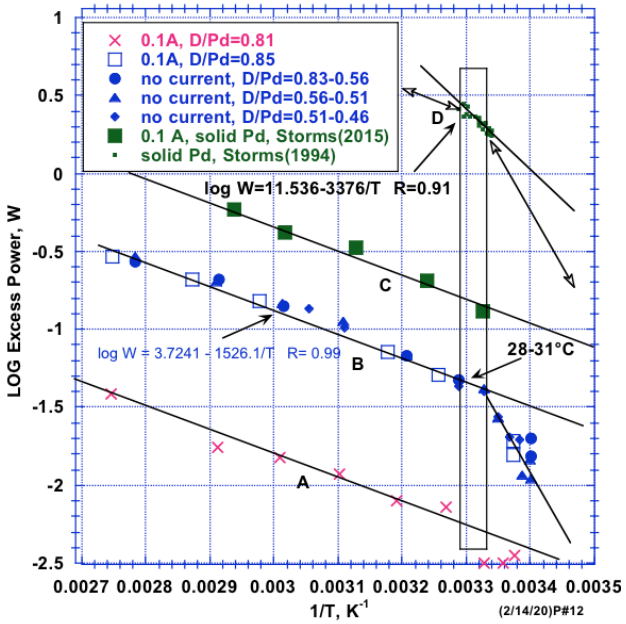


***FIGURE 3.*** *Comparison between the behaviors of different samples of solid and pressed powdered Pd when heated in an electrolytic cell. The designations A, B, C, and D designate independent measurements. The lines drawn through each measurement are parallel, showing that each has the same activation energy.[16, 19]. The study labeled "D" fell in a transition temperature region between two different values for the activation energy, noted as Storms(1994)[20]on the figure.*

### 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.[21] 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.[9] When the increased availability of D is considered, it's important to realize that a million times less D is required to make the same amount of power as would result from a chemical reaction. Consequently, very little D would be required in the lattice structure to support a reaction rate from which significant power could be obtained. How can this expectation be reconciled with the observed behavior?

McKubre et al. [22], as shown in Fig. 4, found an increase in the D/Pd ratio caused the amount of power to increase when a special batch of Pd was used. A similar

behavior was reported by Kamimura et al.[23]. However, a large D/Pd ratio is not always required to cause the production of power, as described by Storms[9] 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.

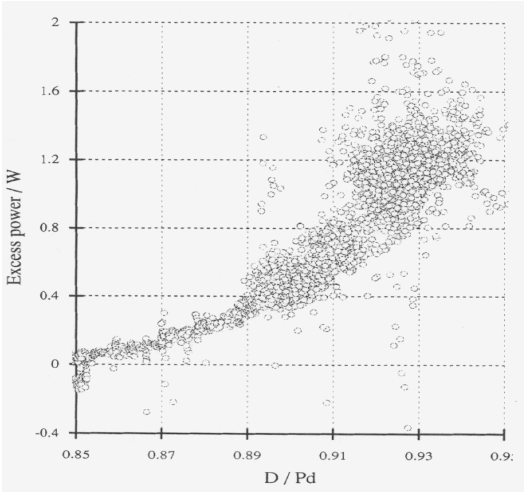


***FIGURE 4**. Effect of D/Pd ratio on power production when an active batch of Pd wire was reacted in an electrolytic cell near 20° C. McKubre et al. [22]*

Notice that essentially no power was produced when the D/Pd ratio was less than D/Pd=0.85 at 20° C. Presumably, if this and the lower compositions had been heated, excess power would have been produced. Therefore, the temperature and D/Pd ratio appear to increase the rate of a process that is already underway but needed the power to be increased above the detection limit of the calorimeter for the process to be made visible.

**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 the phonon energy states[24]. Letts and Cravens[25] found that PdD coated with Au produced extra energy would when it was exposed to 669 nm laser radiation. Storms[26] 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.[27] 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[28] to support his phonon model. On the other hand, this study failed to see the single-frequency effect observed during their previous studies. In addition, the attempted replication of this work by Guffey et al.[29] 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.[30]. Consequently, the role of a special frequency, as claimed by Hagelstein and Letts, is still unknown.[24, 31]

Laser radiation is found to produce antistokes[32] and Maser[33] 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. Of importance, this behavior suggests a coherent process may occur during the fusion reaction. More will be said about this idea in another sections.

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 increased temperature or the increased D/Pd ratio.[5, 34] 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.[35]

Tanzella et al.[36] and the patent by Godes[37] 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 $^4H$. Ignored is the need to add 0.78 MeV of energy as mass to the resulting neutron. The proposed explanation is implausible because this amount of energy is not available in a chemical structure.

Celani et al.[38] applied pulsed current to an electrolytic cell that caused the excess power to increase. They later [39] 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 [40] 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 explained this behavior by using a proposed phase change for which no evidence exists.[41]

Tanaka and Himeno[42] propose electron currents, both spontaneous and applied, could increase the fusion rate by increasing the tunneling process.

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 piece of solid Pd was plated with Pd to produce local islands of a complex structure, as described by Gordon and Whitehouse (G-W)[43]. 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 extra power was too small to cause a significant change in temperature. In each case, DC passing through a resistance wire surrounding the cell is used to increase the temperature. Greater detail will be provided in a future paper.

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 also could be used to calculate the average D/Pd ratio using the equation provided by McKubre and Tanzella[44].

A current reversal after the study caused no change in excess power. This behavior suggests the concentration change caused by electro-migration 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)*

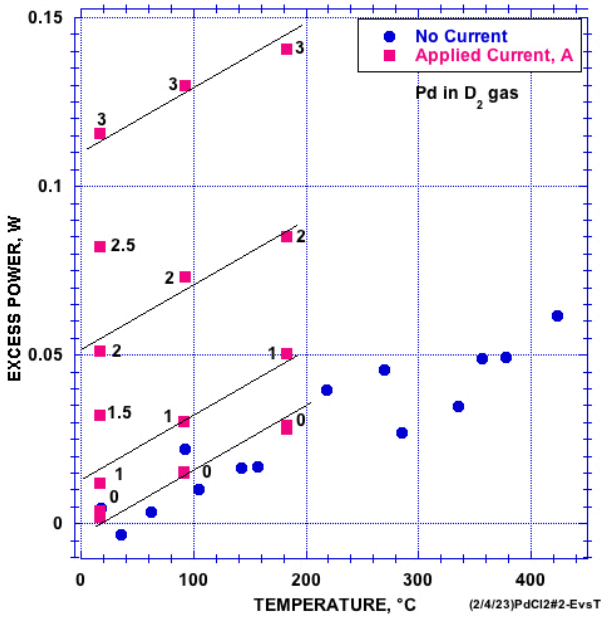

***FIGURE 6.*** *Effect of a steady DC passing through PdD at various temperatures in $D_2$ gas. The amount of applied current is shown in units of ampere(A). The values for "no current" were obtained first followed by the values designated as "applied current".*

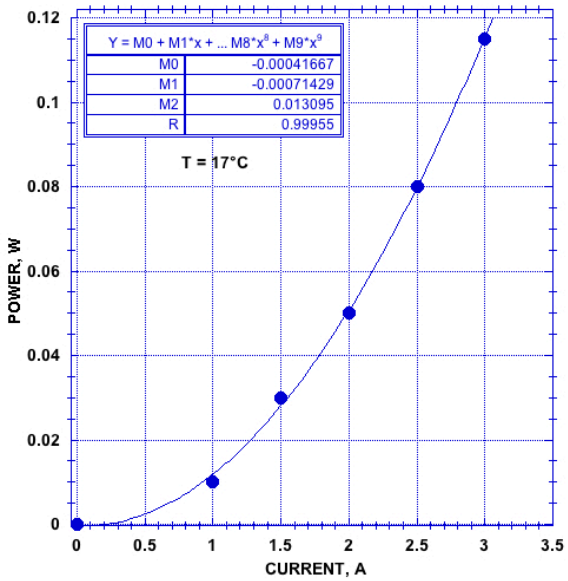


***FIGURE 7.*** *Excess power as a function of applied current at 17°C. Notice that no power is detected in the absence of applied current.*

### 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 helium gas. This creates a problem because the proposed nuclear reaction has no obvious way to conserve momentum when the nuclear energy is dissipated after the helium forms. Two or more nuclear products are required to conserve momentum. Therefore, something else must be emitted along with the new nucleus, as explained in Section 4.0. Also, the description must explain why the energy released by low-energy fusion mechanism does not destabilize the He nucleus as happens when high energy is applied to cause fusion of D+D.

These are not the only conflicts with expected behavior needing resolution. For the He to be measured, it needs to diffuse out of the material and be collected in the surrounding $D_2$ gas. Because helium is known to diffuse very slowly and to have a very low solubility in Pd or PdD, achieving this condition is unlikely unless the source of helium were very near the surface. Otherwise, the helium would be trapped in the PdD structure, which was not measured. Reproducible release of the helium cannot be expected unless it is always created at a similar distance from the surface. Even so, the correct amount of He can be collected only after sufficient time had passed for the creation rate to equal the loss rate, which would require a long time for the average He concentration to achieve a value required for its loss to equal the production rate. No evidence suggests either requirement had been achieved when the measurements plotted in Fig. 8 were made. The loss rate is described next.

The loss rate of He from Pd was explored by Abell et al.[45], who measured the loss of $^3$He from Pd that resulted from the decay of tritium. They found that the ability of He to leave the Pd was related to the concentration of He with a temperature of at least 1300K being required to remove any He when the He/Pd ratio was 0.02, as shown in Fig. 9. The average concentration of He during a typical measurement (Fig. 8) would be near $10^{-11}$ He/Pd and the temperature would be near 300K. Even when the helium is made very near the surface, at least ½ would be retained in the material because some of the nuclear product would diffuse away from the surface. These considerations cause the observed behavior of the $^4$He to be difficult to justify. A solution to this conflict is suggested in Section 4.3.2.

The source of the He can be determined by comparing the measured He/energy ratio to the value calculated from the mass change when D+D is converted to He, which gives a value of $2.6 \times 10^{11}$ He/watt-sec. This value is plotted as the vertical line in Fig. 8 and gives the rate at which He would be formed when the amount of measured energy is compared to the amount of measured helium and plotted as the He/watt-sec ratio in Fig. 8. This histogram compares sixteen separate measurements obtained from four independent studies of the helium found in the gas generated in an electrolytic cell using a PdD cathode. Because the helium trapped in the cathode was not measured, the ratio is expected to be smaller than the true value as is the case. In addition, the combined

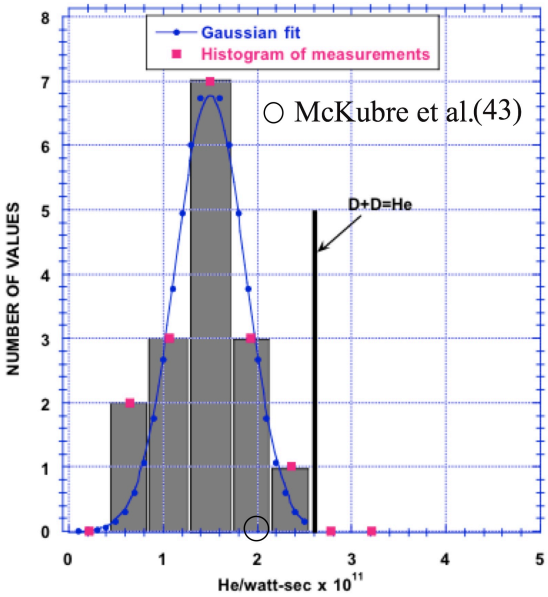


***FIGURE 8.*** *Histogram of 16 measurements by four independent studies showing the amount of helium divided by the amount of energy produced by electrochemical cells containing $D_2O$. A Gaussian error function is fit to the distribution of values. The ratio based on the mass change for the fusion reaction D+D=$^4$He is shown. The value obtained by McKubre et al. [46] 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.*

behavior is consistent with an error function, as would result from small random errors being present in each measurement with seven of the sixteen measurements showing about ½ of the created He being retained in the PdD. Because the amounts of energy and helium are obtained from independent measurements, this kind of agreement indicates

that both energy and helium came from a common source rather than from an accidental combination of random errors in each measurement of energy and helium. Such a consistent combination of errors in the independent measurements of energy and helium would be very unlikely to occur by chance, especially when the measurements are consistent with the required ratio based on the mass change.

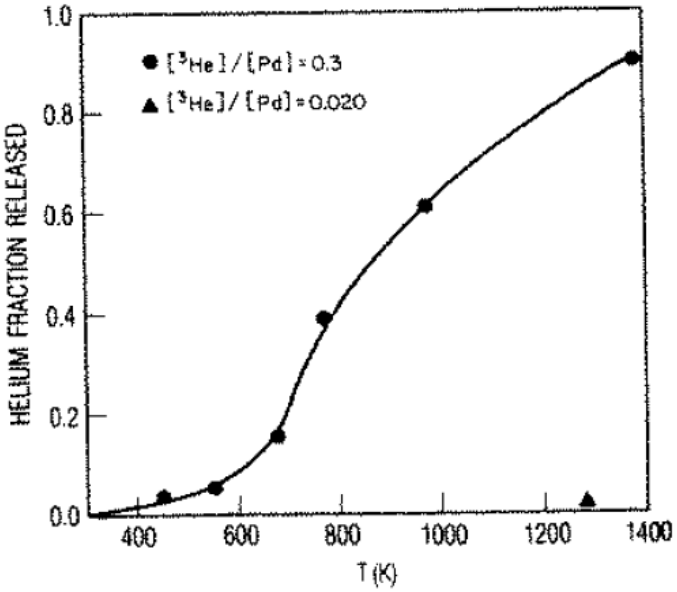


***FIGURE 9.*** *Fraction of helium released as a function of temperature for two different He/Pd ratios. From Abell et al. [45]*

Unlike the measurements compared in Figure 8, McKubre et al.[46] measured the helium produced by a sample of special coconut charcoal containing small particles of Pd heated in $D_2$ gas that was supplied by Case.[47] The amount of generated power was measured using two different kinds of calorimeter: gradient and differential. The amount of helium was measured in real time using a mass spectrometer. The consistent increase of the power and He content shows that steady-state had been achieve. 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. 10 as the amounts of helium and energy both increase with time. Good agreement with other measurements is shown when the average He/watt-sec ratio (Gradient in Fig. 10)) of $2.0\pm0.8\text{x}10^{11}$ is compared to the values obtained using electrolysis, as shown in Fig. 8. However, the failure of other sources of charcoal to support the fusion reaction suggests the fusion reaction may have occurred in the charcoal itself rather than in the Pd. All of the helium retained in this sample could be flushed out under a vacuum after being repeatedly reacted with $D_2$, thus demonstrating that the amount of energy produced by each He formation matched the mass loss resulting from D+D fusion. The large number of values showing a consistent relationship gives confidence in these values representing the entire He and energy made by a fusion reaction involving deuterium.

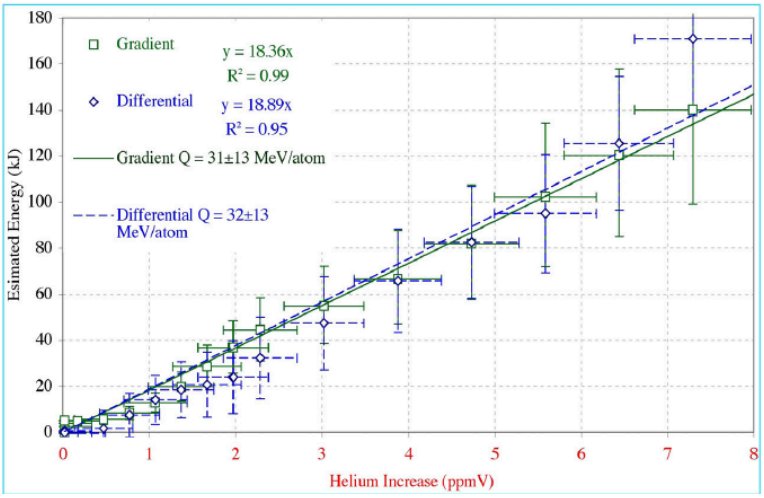


***FIGURE 10**. Energy and helium were made by a special batch of coconut charcoal to which 5% Pd was applied as fine particles and heated near 243°C in $D_2$ gas while energy and helium were measured, as reported by McKubre et al. [46]*

### 3.7 Tritium production

Tritium is a minor nuclear product that is produced by cold fusion on rare occasions when certain conditions are present. Nevertheless, even its occasional presence demonstrates the occurrence of an unusual nuclear process where none is expected. Unlike the tritium produced by high-energy fusion (hot fusion), this tritium is not accompanied by an equal number of neutrons. Instead, the tritium/neutron ratio favors tritium, as shown in Fig. 11. Whether the wide range in values results from an error or because another variable is operating is difficult to determine. Nevertheless, the answer to this question would provide another insight into this unusual nuclear reaction, as discussed in a later section, thereby providing further support for the purposed explanation.

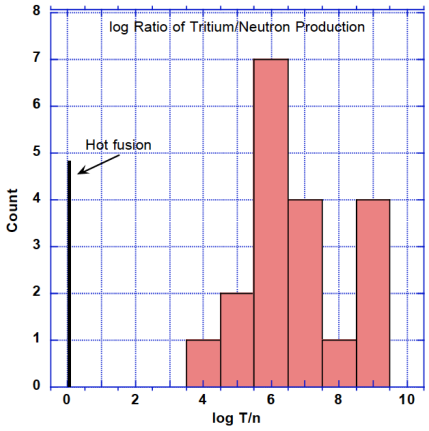


***FIGURE 11.** Histogram of published measurements of the log tritium/neutron ratio. The measured log T/n resulting from hot fusion is also plotted. The values are from Table 6, "The Science of Low Energy Nuclear Reaction".[5]*

### 3.8 Radiation

Radiation dissipates energy from most nuclear events. Although frequently sought, radiation is seldom detected outside the apparatus when cold fusion occurs. This apparent absence 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 to study and to use.

#### 3.8.1 Ion emission

People naturally assumed the observed helium gas (Fig. 8) is emitted with most of the nuclear energy, in the manner of normal alpha emission. Karabut et al.[48](KK) measured the ion spectrum produced when gas discharge occurred 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 even 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. Photons were emitted with laser-like characteristics. This behavior is not typical of a "normal" nuclear process.

The relationship between the peak number and the ion energy for all of the values reported by KK is plotted in Fig. 12. Two different behaviors are seen, with each showing a linear relationship between ion energy and sequence.

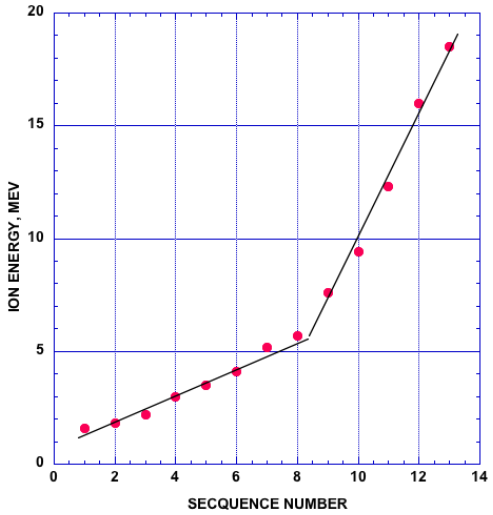


***FIGURE 12***. *Ion energy vs number in sequence reported by KK.*

As can be seen in Fig. 13, the flux of the ions decreases as the energy is increased to give a linear relationship when the log of the peak height is plotted as a function of

peak energy for ion energy up to 6 MeV. Ions with higher energies show even fewer emissions. The implications of this behavior are discussed in Section 3.8.

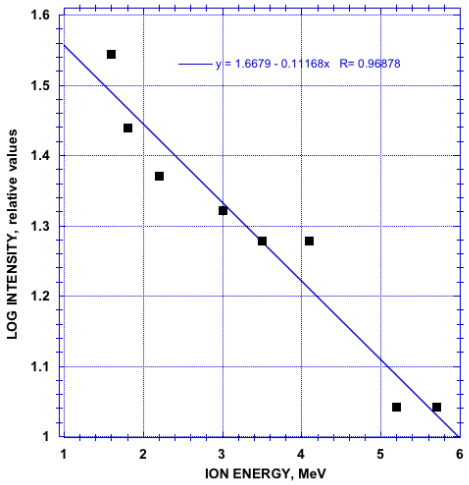


***FIGURE 13.*** *Log of relative intensity of ion emission vs energy reported by KK for energy below 6 MeV.*

Eight years later, Storms and Scanlan[49] (SS) measured the ion spectrum but over smaller range of energy (Fig. 14), again produced by gas discharge while using a silicon barrier detector. This time, absorbers were inserted between the source and the detector to reveal the true nature of the ions and to demonstrate that they were not the result of "noise" created by the electric discharge. Pulses caused by electronic noise would not be changed by the insertion of such thin absorbers. Instead, the absorber produced a reproducible reduction in the measured energy for each peak that was then used to identify the element being emitted.

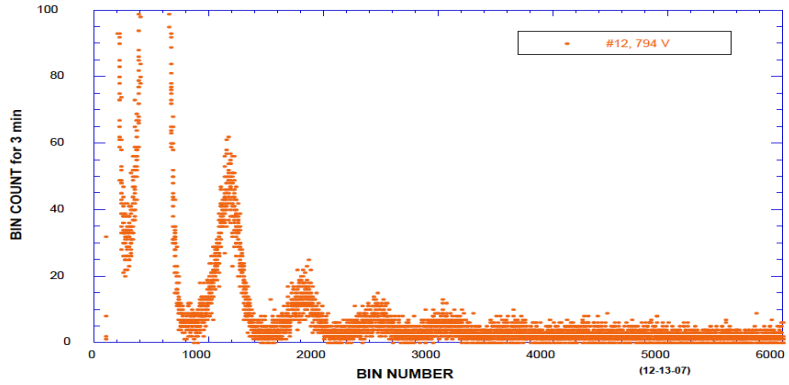


***FIGURE 14.*** *A typical spectrum is produced during gas discharge when either $H_2$ or $D_2$ is used. The bin number was calibrated using the alpha emitted from $Po^{210}$. The counts at BIN number less than 200 are caused by "noise" created by the electrical discharge. (MeV=0.000657 *BIN)*

Confidence in this measurement and the one reported by KK[48] is justified by the good agreement between the reported energy of the radiation and the unique characteristics of the spectrum observed by these two independent measurements. Energy

values reported by KK are compared in Fig. 15 for a similar energy range with the first peak in the sequence given a value of 2 so as to cause the least squares equation to extrapolate near zero energy at sequence # zero. The difference could result from the ions detected by SS being generated at a deeper level, which would result in a loss of energy as they passed trough more material, as indicated by the arrow on the figure.

Both studies also show a log relationship in Fig. 16 between the intensity and the energy of each peak, although the slopes are different. This difference might result from a different ease of access to the fusion site for the nuclei and electrons.

In the case of the SS study

1. The spectrum remained unchanged when either $H_2$ or $D_2$ is used.
2. The energy change caused by the inserted absorbers demonstrate the ions are an isotope of hydrogen, not helium, and the peaks are not the result of electrical "noise".
3. The ion energy is too large to have resulted from a chemical process.
4. Only a fraction of the energy released by a fusion reaction is contained in this radiation.

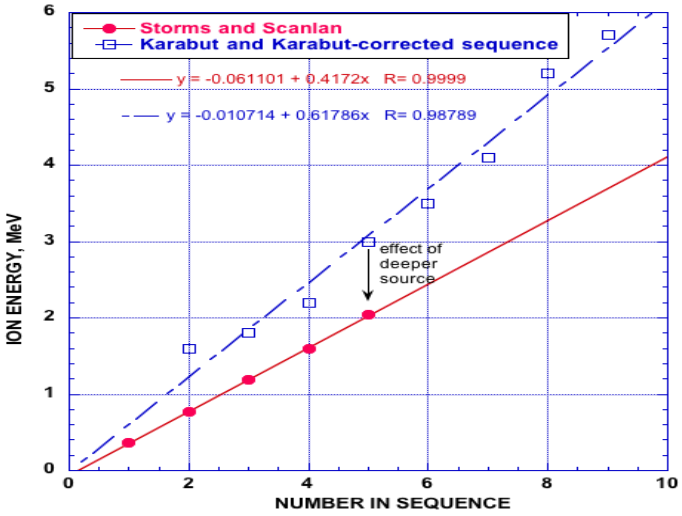


***FIGURE 15.*** *The relationship between the sequence in the spectrum and the ion energy. The values are obtained from Figs. 12 and 14. The arrow shows the effect on the energy caused by passage through an absorbing material. The sequence number for the KK values is corrected to give zero energy at sequence number zero because the first peak in this series is lost in the noise.*

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. The similar width of each peak would result from a small but similar amount of scattering. Of course, other sites might be producing ions but these would be located too deep for the ions to reach the detector. Also, only ions being emitted in a particular direction would be detected. These considerations indicate the ions detected in both studies are coming from a single source located very near the surface.

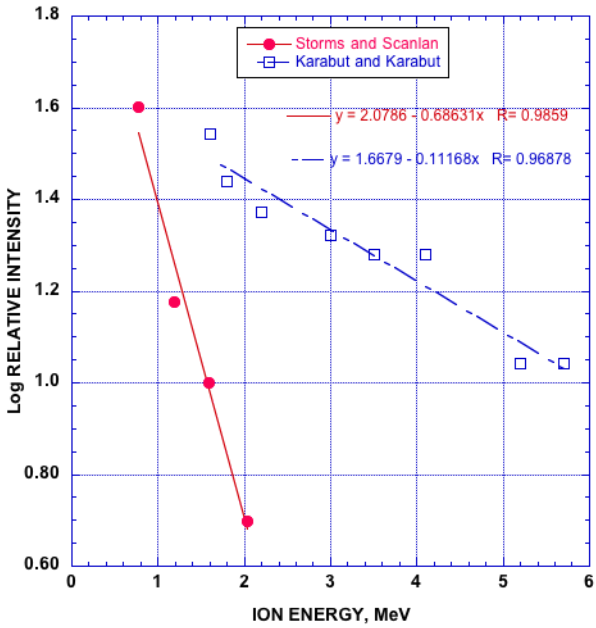


***FIGURE 16.*** *The relationship between log intensity and ion energy. Because the intensity is based on a relative value, only the difference in slope is significant. The values for SS are obtained from Fig. 14.*

Why each peak has the same energy difference from its neighbor is still a mystery. KK found this constant separation to be larger (0.617 MeV) than the value reported by SS (0.417 MeV). Perhaps, the ions measured by KK experienced less energy loss because they were created closer to the surface than the ions measured by SS.

The behavior suggests an unknown process is causing a quantized behavior resulting from each peak being influenced in sequence rather than as the result of a single event involving all of the emissions. The mystery is deepened by the ion energy having no clear relationship to the total amount of energy released by the fusion reaction. An explanation is suggested in the next section.

The very similar behavior of $H_2$ and $D_2$ is an important surprise found by SS. This suggests the same nuclear product can result from both reactants. However, this behavior does not eliminate other nuclear products from being produced at the same time, with these emissions being undetected because their energy would not fall within the range of the SBD. An explanation is explored in a later section.

SS determined the nature of the ions by measuring 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 $^4H$, which is consistent with the observed behavior, was not considered.

When D fuses, 23.84 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 conservation of momentum requires the simultaneous emission of two particles. Where is other particle? Why is the energy

dissipated as many discreet energies? These questions add to the growing list an explanation must answer, as described in Section 4.0.

Ion emission has also been measured by over one hundred studies[50-52] in electrolytic cells using CR-39 to detect their presence and energy. In each case, the resulting spots produced in the CR-39 plastic were assumed caused by $^4$He emission and the energy was calibrated using the alpha emission from sources having known energy. In view of the studies of KK and SS, these spots could instead have resulted from $^4$H emission. The $^4$H ion would have produced a different size spot compared to that produced by an alpha of the same energy. Consequently, the claimed energy based on this calibration could be incorrect. This possibility needs to be given serious consideration.

The emitted $^4$H ions have sufficient energy to cause transmutation and hot fusion reactions from which unexpected radiation might result. This possibility will be discussed later in the paper.

**3.8.2 Photon emission**

Karabut et al.[35] used photographic film to record highly focused beams of photons being emitted from the cathode. In addition, they[53] measured the photon energy and found the radiation to have laser-like behavior. The photon energy is consistent with a nuclear source as well as having energy typical of X-rays. Some of this radiation even resulted from radioactive decay that occurred over many hours. The pattern of the photon emission was similar 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. 17. Apparently, photons having a wide range of energy are emitted as tightly focused beams in random directions with different intensities. The implication of this behavior is complex and important, as discussed in Section 4.3.

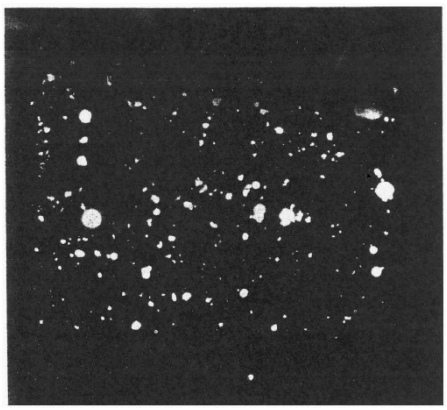

***FIGURE 17.*** *Spots are produced on photographic film by photons that pass through 0.5 mm of aluminum. A similar pattern is produced when 2 mm of Pb is used, which indicates the radiation has a wide range of energy.*

Szpak et al.[54] also used photographic film to detect photon radiation when it appeared to be emitted from a single well-defined source, but in this case when an electrolytic cell was used. Once again, photon radiation having a similar unusual behavior is seen.

Because people would not expect to see highly focused beams of photons to result from a nuclear process, methods able to detect focused radiation have not been used by most previous studies when photon and electron radiation were detected, thereby missing this unusual behavior. This oversight is important because the unique behavior has the potential to reveal the mechanism by which the nuclear energy is released, as described next.

### 3.8.3Electron emission

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

Recently, Gordon and Whitehouse (G-W)[43] measured a strong electron current being emitted from a deposit of Pd exposed to $D_2$ or from a deposit of Fe[55] 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 cold fusion. This measurement might provide the final missing piece of the puzzle and open the door to a new understanding about how nuclear energy is dissipated and how momentum is conserved when cold fusion occurs.

To test whether this electron emission is related to the excess power produced by cold fusion or not, I studied the relationship between electron emission and heat production using an active material and a calorimeter described in a previous paper.[16] A piece of Pd was activated by applying a layer of Pd using the codeposition method[56] (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-emitter assembly is shown in Figure 18. 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.

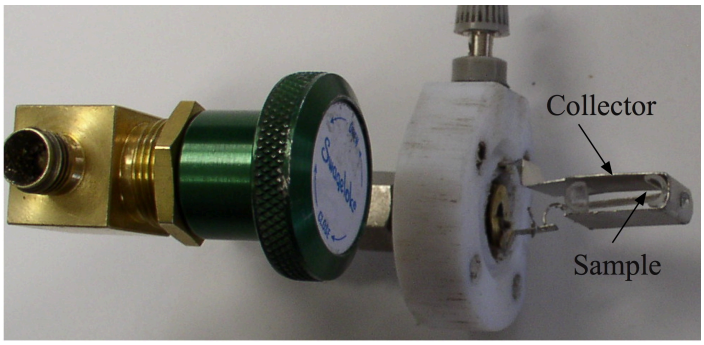


***FIGURE 18.*** *Photograph of the sample-collector assembly.*

The material was heated in $D_2$ gas over a temperature range, as shown in Fig. 19. Excess power and electron current are both increased by increasing the temperature, suggesting a common cause.

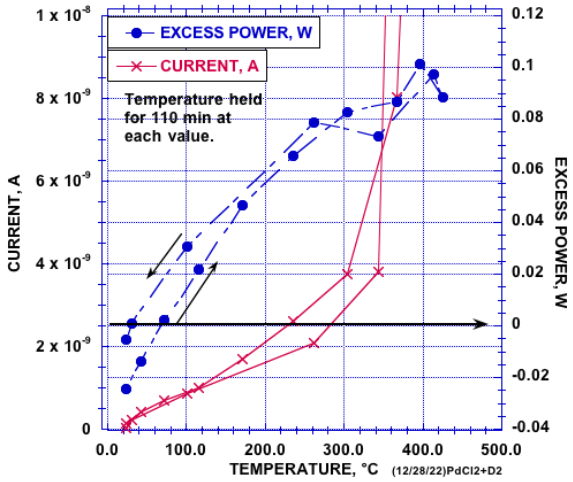


***FIGURE 19.*** *Excess power and emitted electron current are measured as a function of temperature when co-deposited Pd is heated in $D_2$ gas. An external potential was not applied between the two electrodes. The arrows indicate the sequence of the measurements. The excess power was measured before 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 the heat energy can be measured regardless of where it is produced. With two different chemical environments being involved, the temperature could influence these two locations in different ways. In addition, current could result when ions are created in the $D_2$ gas by the emitted electrons. Also, some current could be added by thermionic emission when the temperature is increased. For the sake of this discussion, 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 the 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, shown in Fig. 20, 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 be measured 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 of the sample is made positive relative to the collector, electrons would be returned to the sample when the applied potential is equal to or greater than their energy. The reduction in the emitted current (Fig. 20) as the voltage is made more positive relative to the sample reveals the emitted 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[43] 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 so many energetic electrons produced?"

Figure 21 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.

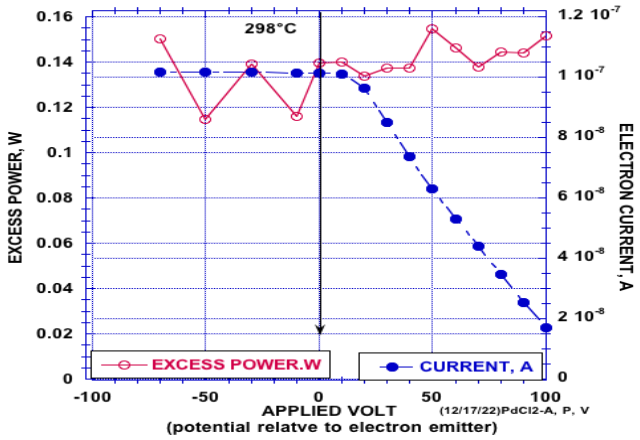


***FIGURE 20.*** *Electron current and the excess power at a temperature of 298° C when the voltage between the emitter and collector is changed. The potential is shown relative to the sample, thereby causing the electrons to be emitted with additional energy from the sample when the indicated voltage is negative.*

Based on the measured power, the total number of fusion events is $3.9 \times 10^{10}$ fusion/sec. The measured current shows that electrons manage to escape at $6.2 \times 10^{11}$ electrons/sec, which is the lower limit to the total number of electrons being released from the nuclear events. If we assume ½ of the emitted electrons cannot be measured because they are emitted toward the interior, the ratio of the (number of electrons)/(number of fusion events) is 32. This ratio is important because it shows that more electrons are emitted than the number of fusion events but far less than is calculated in section 4.3.3. The difference results from most of the emitted electrons being stopped before they can exit the material.

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.

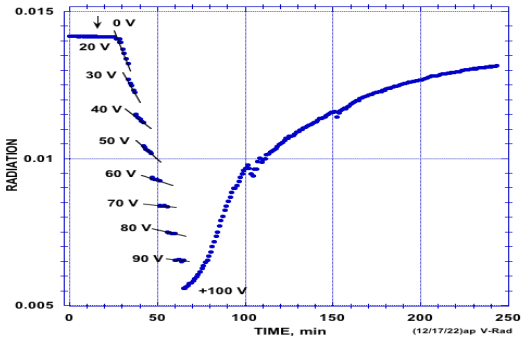


***FIGURE 21***. *Effect of time on the voltage measured across a series resistor when the voltage across the cell is changed as shown in Fig. 20. The ordinate designated as radiation represents a relative value for the electron current*

## 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, crystal formation rules, and all chemical understanding apply to cold fusion. Reason: Cold fusion occurs 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 cold fusion. Reason: cold fusion 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 cold fusion regardless of the material being used as the host or its treatment. Reason: Nature typically has a single mechanism for causing various phenomena.

5. The mass-energy is dissipated by the simultaneous emission of $^{4}H$ and many electrons in opposite directions. Reason: The emission of $^{4}H$ and electrons has been observed when cold fusion occurs. This assumption allows the momentum to be conserved during the observed emission without the need to introduce new assumptions. Because this assumption describes the main conclusion resulting from this work, it remains an assumption until it has been verified by other studies.

**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 as an unexpected consequence of a novel chemical arrangement involving electrons and hydrogen nuclei.

These events do not take place informally throughout the material but only at certain unique sites. These sites allow the required nuclei and electrons to accumulate as the result of normal chemical processes. The nuclear events take place after this assembly has formed following a short but unknown amount of delay.

In addition to fusion, the nuclear process can result in secondary nuclear reactions, identified as transmutation reactions with the surrounding nuclei, or "hot fusion" reactions can occur when the energetic emission interacts with the surrounding hydrogen nuclei. These rare reactions might produce radiation and various decay products that can be mistaken to result directly from the fusion reaction itself, thereby adding complexity and confusion. Storms and Scanlan[57] reported seeing radiation that might have resulted from such sources. These secondary nuclear reactions are not discussed here. Nevertheless, the occasional emission of neutrons at a significant rate needs to be evaluated in view of these other possible reactions.

**4.2.1 Nuclear-active-environment *(NAE)***

Cold fusion is proposed to require a new kind of structure in which a nuclear process can take place without any 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 cold fusion, as has been frequently demonstrated. The challenge is to identify the NAE and then find ways to create more of it.

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 cold fusion works, and eventually to 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 same location at the same time is not sufficient for fusion to occur. In addition to the D(H) nuclei, a very unusual and complex structure involving electrons must form such that the Coulomb barrier can be reduced enough for nuclear interaction to start[1]. 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 a different 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 to accept, 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 that exist in every sample of Pd. If the NAE 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. However, the tetrahedral sites can briefly contain D atoms as they pass through to different locations at the result of self-diffusion. Such random events would not be expected to sustain a unique nuclear process at the observed rates.

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 briefly caused only by the chance motion of the D(H) as the 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.

Metal atom vacancies can occasionally occur in the Pd sublattice but 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[41, 58, 59] that vacancy tubes are present in PdD is very weak because the claim by Fukai[60] on which this idea is based could not be replicated.[61] Because these tubes would have the same chemical properties as a Pd atom vacancy, their occupancy would suffer from the same limitation.

This leaves cracks or gaps that are formed as the accidental result of stress relief. These gaps, being unaffected by the requirements that apply to a crystal structure, could contain a wide range of chemical conditions. Because gaps are always present in material

[1] For the purpose of this discussion, an assembly of electrons is proposed necessary to overcome the Coulomb separation between the hydrogen nuclei. However, if other ways to accomplish this goal are suggested, they must also be consistent with the observations and chemical requirements described here.

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 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.[19, 62] As a result, when a piece of Pd is found to support cold fusion, most 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 most samples are dead. Also, very pure Pd is found not to support cold fusion. Instead, 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 in JCMNS.[9] A copy is available at www.LENR.org.

### 4.2.2 Nuclear-active-structure (NAS)

The actual arrangement of atoms and electrons that experience fusion is called the nuclear active structure (NAS). The NAS forms at special locations in the NAE. After a NAS assembles in the NAE, fusion of the NAS can occur after a slight delay. The structure eventually "explodes" as the resulting mass change is converted to energy. The NAS can reform in the same NAE as the hydrogen nuclei and electrons again reassemble. The process is revealed as hot spots that wink off and on in the video provided by Szpak et al.[63] 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 the active material. The greater the number of NAS in each NAE and the greater the number of NAE in the material, the more power would be produced. A successful amplification of this source of energy would require treatments that increase the number of NAS and the rate at which they reform in each NAE after they are destroyed by each fusion event. This realization will influence the design of a useful energy generator.

### 4.2.3 Difference between hot fusion and cold fusion

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 using the kinetic energy of the nuclei as they encounter each other, usually in 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 resulting nuclear product fragments into two different pairs of nuclear products, as shown in Fig. 22, with nearly equal probability even at the lowest applied energy. The electrons present in the material can add local screening to increase the very small rate of the hot fusion reaction over the rate caused in plasma, during which this screening is absent, as shown in Fig. 23.[42, 64] 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 approach velocity is decreased so that screening has more time to act. This screening effect is never 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 during hot fusion is possible in a chemical structure. This kind of screening does not apply to the cold fusion process during which the amount of screening is far greater because the nuclei can remain in close contact for a longer time.

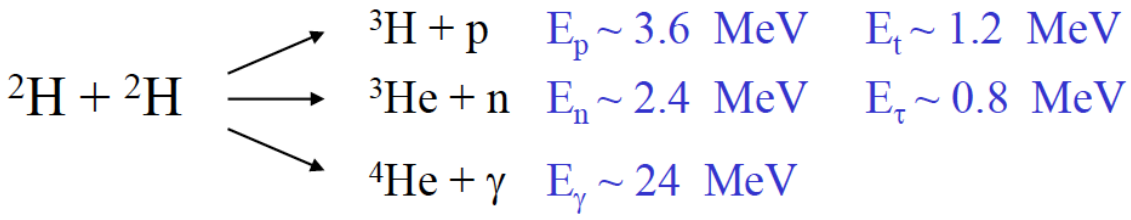


***FIGURE 22.*** *Energy of the emissions resulting from hot fusion between deuterons as provided by Czerski[65] The emission of $^4He$ and a gamma has a very low probability and is never found to occur during cold fusion.*

In the case of cold fusion, the electrons must first concentrate near the hydrogen nuclei in numbers sufficient to reduce the Coulomb field. Now we have a problem because electrons are not known to concentrate this way. Even when electrons concentrate to form chemical compounds or crystals, the electron structure keeps the nuclei far apart. For cold fusion to occur, the electrons need to reduce the separation. This requires a new kind of electron interaction instead of a variation in the hot fusion mechanism. This realization is one of the important consequences resulting from this discovery.

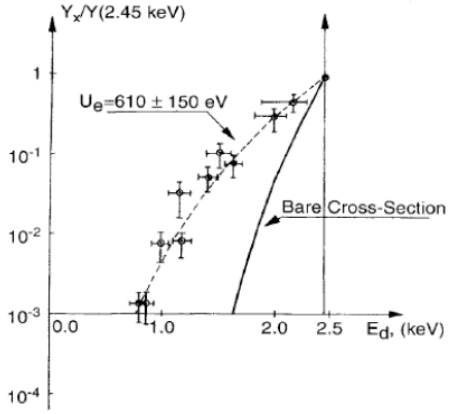


***FIGURE 23****. The result of D+ bombardment of Ti with indicated kinetic energy to produce the rate of hot fusion relative to when a kinetic energy of 2.45 KeV [66] is applied. A calculated value for the screening potential ($U_e$) is shown. The bare cross-section is obtained when fusion occurs in plasma. The absolute fusion rate at this energy is near the detection limit, to which electron screening adds very little additional rate.*

However, the $^4H$ and the other nuclear products are emitted during cold fusion with sufficient kinetic energy to cause hot fusion if they were to encounter a D or H in the

surrounding structure, thereby producing a mixture of hot and cold fusion products. Confusion could result if this mixture were not properly evaluated. The claims for fractofusion being the cause of the occasional energetic radiation that might, instead, be the result of cold fusion.[67-69] In this case, the brief cold fusion process that initiates the easily detected energetic radiation would be too small for its unique signature to be detected.

### 4.3 Nuclear Products

Based on the data summarized in Fig. 8, $^4$He is the main nuclear product from which the measured energy results. Storms and Scanlan[9] showed that helium is not emitted directly from the nuclear event, as discussed in Section 3.8.1. 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 said to rapidly decay by neutron emission when it is formed at high energy.[70, 71] Because this conclusion is used to reject the claim made here, the decay characteristics of $^4$H need to be examined, especially given the measurements shown in Fig. 15 and the possibility that the decay mode might change when the isotope is made at low energy. After all, the decay mode of the nuclear product resulting from D+D fusion changes when the applied energy is typical of cold fusion, as described in Section 4.2.3.

#### 4.3.1 Decay mode of $^4$H

This paper is not designed to evaluate the existence of $^4$H, which has been done elsewhere.[70] So, I can only provide some ideas worthy of future examination. As a start, I will describe a few basic observations.

The $^4$H nucleus is claimed to form for a short time when liquid deuterium is bombarded by $^3$H+ ions having energy of 57.5 MeV.[71] Emissions of energetic p, n, and $^3$H are observed. The $^4$H is proposed to form when the deuteron transfers a neutron to the $^3$H causing an energetic p to be emitted. The $^4$H then quickly sheds the neutron causing the $^3$H and neutron to be emitted in opposite directions. I suggest the observations on which the creation of $^4$H is based also can be explained by the fragmentation of a deuteron into p and n without the formation of $^4$H. The many calculations of the energy state of $^4$H are based on this and similar observations when high energy was applied. Still unknown is whether a stable energy state is available when the isotope is made at low energy in the presence of an electron cloud.

#### 4.3.2 Consequence of $^4$H formation

How might $^4$H be produced instead of $^4$He while helium is found in the environment? This question needs to be combined with another question. How can $^3$H (tritium) be produced by the same mechanism as $^4$H 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 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[72] 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 surrounding 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 without the need for additional assumptions?"

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 an energetic deuteron along with the same energetic electron emission. In summary, the overall process appears to convert one hydrogen isotope into another as the result of fusion involving electron screening and electron capture.

The small D impurity in normal hydrogen would contribute a small amount of D+e+H fusion but this would be too small to account for the amount of tritium detected. Also, the amount of power observed when normal H is used cannot be explained by the fusion between an occasional D nuclei. Likewise, the small amount of H in the purified D would not have a detectable result. Different explanations must be sought.

**TABLE 1**

Proposed reactants, nuclear products, and energy for each reaction produced by cold fusion[11]

| | |
|---|---|
| (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 decay) + ν | <19 MeV |
| (T+e+H) = $^4$H = $^4$He + e (fast decay) + ν | <21 MeV |

All of the initial nuclear products are accompanied by the emission of many electrons.

When only 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 because the main energy-producing reactions (D+e+D and D+e+T) would have a lower probability in Pd as the result of the nuclear products diffusing rapidly from the active site.

The few neutrons detected when tritium forms result from fusion between the tritium and deuterium nuclei. The wide range in the T/n values (Figure 11) 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 the neutron emission.

The conflicting behavior shown in Fig. 8 can now be explained. Instead of helium being essentially trapped after it is made, the nuclear product is an isotope of hydrogen with the ability to rapidly diffuse out of the material. A variable fraction of the $^4$H might decay to $^4$He before it could diffuse out of the material. Consequently, the amount retained by the PdD would result from the relationship between the diffusion rate of $^4$H and its decay rate, not only from where the fusion reaction occurred in the material.

Two more questions need answers. How is the momentum conserved and where is the fusion energy that is missing from the emitted $^4$H?

***4.3.3 Implications of the proposed electron emission***

The search for the mechanism by which the released nuclear energy is dissipated has resulted in many suggestions. For the sake of discussion, let's assume this energy is dissipated by the emission of electrons such as are detected as an electron current in the LEC.[43] (Assumption #5) After all, if an assembly of electrons were required to shield the Coulomb barrier, these electrons would be expected to share the energy state of the combining nuclei. Hence, they would be available to dissipate this energy as an emission of electrons. What implications result from this assumption?

By combining the conservation of momentum equation with the known kinetic energy of the $^4$H and the total energy released by fusion, the number of electrons being emitted, and their energy can be calculated. The following equations describe the conditions required when momentum is conserved by the emission of $^4$H in one direction and all of the electrons involved in the creation of the $^4$H in the opposite direction.

$A*M_e*V_e = M_h*V_h$ where A is the number of electrons being emitted for each $^4$H emitted, $M_e$ is the mass of an electron, $V_e$ is the average velocity of the emitted electrons, $M_h$ is the mass of $^4$H, and $V_h$ is the velocity of the $^4$H being emitted in the opposite direction to the electrons.

$K_e = \frac{1}{2}*A*M_e * V_e^2$ = total kinetic energy of the emitted electrons = $(23.84- K_h)x10^6$ eV
$K_h = \frac{1}{2}*M_h * V_h^2$= kinetic energy of $^4$H (Values obtained from Fig.15.)

$M_h$ = mass He + mass e = 4.002603 +0.000548 = 4.003251 amu
This mass is the lower limit because a small amount of mass is lost as energy when the electron and antineutrino are emitted as $^4$He is created by beta decay of $^4$H.

These equations can be reduced to

$A = (4.003251*K_h)/(0.000548*(23.84-K_h))$ = total number of electrons emitted with each $^4$H that has a measured kinetic energy of $K_h$.

$(23.84-K_h)\bullet 10^6/A$ = energy of each emitted electron

Values of $K_h$ for each energy peak is obtained from the KK values, as described by the least squares equation, as shown in Fig. 15. These values are chosen because they appear

to be closer to the actual emitted energy than the SS values. The calculated values for the kinetic energy of each electron and for the number of electrons (A) emitted from each fusion reaction are plotted in Fig. 24. Because the nuclear product is emitted with a discrete flux and energy, so to are the electrons emitted with a similar characteristic, but opposite in magnitude and direction.

As can be seen in Figs. 13 and 16, the lowest energy of the emitted $^4$H has the largest flux compared to the other ion emissions. Fig. 24 shows that, at the same time, the lowest flux of electrons is being emitted, but with the highest energy compared to all the other electrons. In addition, while each peak of the $^4$H emissions is separated by an equal amount of kinetic energy, each peak is also separated by an equal number of emitted electrons. This extraordinary behavior has several implications.

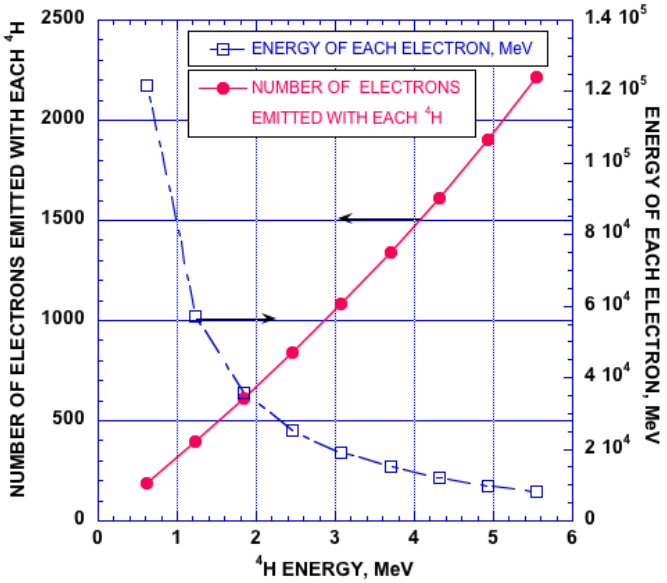


***FIGURE 24.*** *The number of electrons and their energy that are emitted with each $^4$H so as to dissipate the fusion energy while momentum is conserved. The values are obtained using the equation for $^4$H energy shown in Fig. 15 based on the KK values.*

In order for the momentums to be conserved, all of the emitted electrons must travel in the same direction while taking a direction opposite to the corresponding $^4$H emission. This means the electrons must form a tightly focused beam. Only ions that took a particular direction regardless of their energy would be detected. This requirement suggests the gap from which all of the detected ions originate is not symmetrical but has a preferred direction to its shape.

Because each peak of $^4$H is separated from its neighbor by the same number of emitted electrons (216) and by the same amount of kinetic energy (0.617 MeV), this suggests that a regular array of energy levels separated by the same number of electrons exists in the assembly after fusion has taken place. These values are uncertain by the unknown amount because energy is lost by the $^4$H during its travel though the material.

The existence of multiple energy states with each having a different probability of being formed suggests that a delay exists in the decomposition of each energy level such that additional electrons have time to accumulate, thereby allowing the next unstable

level to form with a greater number of electrons but with a reduced probability. As a result, a relatively larger number of electrons would be emitted with each having less energy as each energy level became populated and then slowly decomposes. This is a unique process that needs to be explored.

These electrons are proposed to generate the observed photon radiation as Bremsstrahlung. The description of this process provided by Swartz and Verner[73] does not apply. Instead, beams of electrons are emitted in random directions from each NAE. The energy of these beams would be converted to photon radiation as they pass through the surrounding material. These photons would travel in the same direction as the electron beams and could result in the photon beams shown in Fig. 17. Because the electrons have a wide range of energy, the resulting photons would also show a wide range, as is observed.[66, 74-76]

The resulting electron spectrum is plotted in Fig. 25 where the relative intensity is plotted as a function of election energy when emitted with the corresponding $^4$H. This spectrum results by dividing the intensity of the electrons emitted with each $^4$H ion, as plotted in Fig. 22, by the total of all the electrons emitted for this range of $^4$H energy. The result is a hypothetical and idealized electron spectrum. The average energy of the emitted electrons is near 0.03 MeV with most of the electrons having energy between 0.01 and 0.02 MeV. Consequently, this emission would create and be affected by an applied magnetic field.

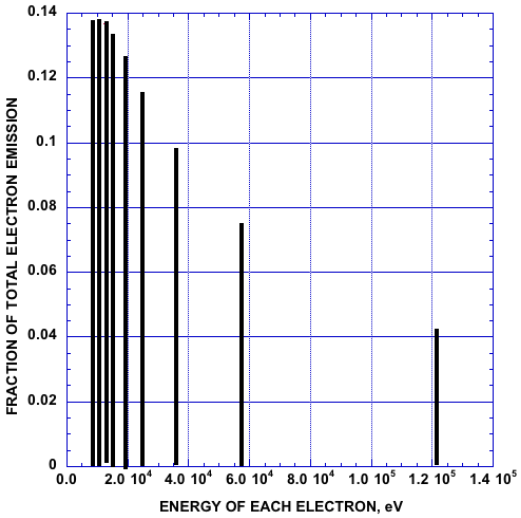


***FIGURE 25***. *Calculated spectrum of the election energy before the emitted electrons have passed through any material. The fraction of the total electron emission flux is shown for each $^4$H peak with energy below 6 MeV, as reported by KK. This spectrum of electron emissions is expected to occur at the same time the $^4$H ions are emitted.*

### *4.3.4. Implications of the need for electrons to assemble*

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 a flux of hydrogen nuclei, as has been described previously[17]. 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 move and concentrate near the negative polarity as the result of electromigration, identified frequently as the Coehn Effect,[35] thereby further increasing the availability of nuclei.

Support for this proposed mechanism is provided by Godes[36], Celani et al.[39] and Staker[77] 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.

### *4.3.5 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 normal H that does not contain extra 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 rate of tritium plus deuterium fusion increases. A mixture of D and H will produce tritium at the fastest rate.
3. Use of either D or H will produce nuclear energy with the H producing less power than D when the same number of NAS is present.
4. 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. The use of normal H will produce a larger but variable He/energy ratio compared to D.
5. An electron current passed 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 use of either D or H will produce a flux of emitted electrons in different amounts and with different energy.
8. 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.
9. 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.

10. 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 with a coherent relationship to the other electrons.
11. The fusion process involves a series of equally separated energy states that decay with a short half-life to release its energy as the kinetic energy of many electrons and the nuclear product, each of which is radiated in opposite directions.
12. Products produced by the hot fusion mechanism will be occasionally observed, especially when the D concentration is large.

**5.0 DISCUSSION OF THE NUCLEAR PROCESS**

Because the conditions required to cause cold fusion are unique to nuclear physics, the process has been very difficult to accept and understand. Enough evidence has now been acquired to show that cold fusion is real and not a mistake. The next step requires this evidence to be assembled into a useful description of HOW the process works and apply this understanding to the creation of a practical source of energy. For this goal to be accomplished, we need to make the critical measurements with greater skill and to test the suggested predictions with an open mind. Only then would a mathematical description of WHY the nuclear mechanism works is 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 can be explained by a logical relationship, which I propose as a model with predictions by which it can be tested.

Cold Fusion produces $^{4}He$ as the nuclear product from which most of the observed energy originates. This nucleus does not fragment when produced in a chemical environment, in contrast, how it behaves when it is made by the application of sufficient kinetic energy. What causes these contrasting behaviors?

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 interacted with the nuclear energy states to lower the Coulomb barrier would be able to dissipate part of the mass change as energy when they are emitted from the assembly after the fusion process had made mass-energy available. This emission could be viewed as a nuclear explosion that sends the surrounding electrons in directions opposite to that of the nuclear product. As the last of the electrons are emitted, one could be captured by the final nuclear energy state to form $^{4}H$. As a result, this final nuclear product can be assumed not to 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[78] provided a partial description of this process in the form of the hydrino. Rathke[79] and Meulenberg[80] 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[81], 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 structure containing many electrons and a few nuclei the EVO. Fox[82] and Jin[83] explored this idea in greater detail.

Rambaut[84] describes this electron structure as a magnetic monopole. Hubler[85] provides a different explanation for the same behavior. Ball lightning has a similar characteristic but on a larger scale.[86-89] 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 the 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 to the resulting neutrino. The frequently observed transmutation reactions are made possible by the kinetic energy released by the fusion reaction, thereby explaining how the huge Coulomb barrier can be overcome. Some of the observed radiation could result when the transmutation products experienced radioactive decay or when local hot fusion resulted from the emission of the cold fusion products.

**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, including by nano-machining.

The fusing structure is proposed to consist of two nuclei of any hydrogen isotope and many electrons. To cause fusion, this structure must cause at least two nuclei to get close enough for their nuclear energy states to interact. This reduction in separation, which can be called shielding or tunneling, is caused by the assembly of many electrons that form an unusual energy state with each other and with the nuclei. The creation process must be consistent with the rules that apply to chemical processes because, initially, the process does not anticipate nuclear interaction. This means the assembly process must be exothermic. Otherwise, its formation would not be spontaneous and consistent with the requirements of the Second Law of Thermodynamics. This realization focuses attention to a new kind of electron interaction that is able to offset the mutual repulsion caused by their charge. According to the behavior shown in Fig. 15, this energy state has of a series of levels, each of which has a delay or half-life for its formation and decomposition into the final fusion product. This conclusion results because a series of energy states are emitted, each of which has a lower probability for its formation as the energy is increased, as shown in Figs 13 and 16. This requires each energy state to have a delay before it “explodes” during which time additional electrons can be added to cause the assembly to be stabilized until the next unstable condition is achieved. Each event

reduces the probability of achieving a structure having a greater number of electrons. Why and how such a series of structures would form is a problem for theoreticians to solve.

The rate limiting process that controls the amount of power involves the number of active sites, and the rate at which electrons and hydrogen nuclei can assemble at each site. Temperature, an applied electron current, and an applied hydrogen flux all affect the assembly process. Once the active structure is assembled, the fusion process is fast compared to the assembly process.

At least, two products associated with the fusion mechanism must be available at the same time to allow conservation of momentum when the released mass-energy is dissipated. The electrons that cause this reduction in separation would be available to interact with the nuclear energy states. As a result, as fusion happens, some of these electrons would have access to the released mass-energy and be able to dissipate this energy as kinetic energy and momentum. These electrons are required to be emitted as a tight beam to conserve momentum. The tight beams of photons shown in Fig. 17 would result from Bremsstrahlung as the electrons pass though the surrounding material. The process is explained at https://en.wikipedia.org/wiki/Bremsstrahlung. This process would cause the photons to have a preferred direction and an energy that depended on the energy of the electron beams.

Because many electrons must surround and interact with the D nuclei in order to lower the barrier and cause fusion, we have another consequence to consider. Electrons do not like to assemble in concentrated assemblies because of their charge repulsion. This means that a new kind of electron interaction must counter this mutual repulsion. The assembly must also have a quantized characteristic in order to explain Figures 14 and 25. Thus, a new kind of electron structure is revealed that I suggest also functions in a normal chemical system but has been ignored because the accepted explanation of chemical behavior could be applied with sufficient success without having to consider this added complexity. The observed production of tritium in the earth's mantel[90, 91] has demonstrated that these nuclear reactions are able to occur even in the normal environment. A description based on a similar assembly of atoms and electrons has been suggested by Goncharov and Kirkinskii[92].

Because the electrons are not emitted by the beta decay mechanism, i.e. by the decomposition of a neutron, 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.

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 deuterium. The same mechanism, including the emission of electrons, applies equally to all isotopes of hydrogen with only the nuclear product being affected by which isotope is caused to fuse.

This description is able to explain most of the observed behaviors by answering a series of questions using consistent logic without violating any accepted law of Nature. Many predictions are provided to test the five assumptions. In addition, a novel kind of

interaction between the electrons in a material is identified and a few implications are described without using mathematical assumptions.

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, cold fusion needs only a special condition formed easily within an ordinary material, such as palladium or several other materials. The required conditions might also be made in large amounts with reproducible behavior using nano-machining. The discovery of how to make cold fusion 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.

**ACKNOWLEDGEMENT**

This work would not have been possible without the financial support and encouragement provided by Brian Scanlan. Bruce Steinetz and Larry Forsley also provide important encouragement and made possible the financial support provided by NASA. My wife, Carol, supported my efforts by being patient and loving. I'm grateful to George Hulse and David Nagel for encouraging me to clarify the description. Many of the cited papers can be found at www.LENR.org, thanks to the efforts of Jed Rothwell.

**APPENDIX I**

Summary of the implications.

1. $^{4}$He is not made directly by the fusion process.
2. $^{4}$He is not emitted with energy.
3. $^{4}$He results from the fast beta decay of $^{4}$H.
4. $^{4}$H is created and emitted with energy when D fuse
5. A complex process involving electron assembly operates at unique sites in a material.
6. A complex process involving uniquely related energy states causes the cold fusion event.
7. Tritium is made when D+H fuse.
8. H+H fusion makes less energy compared to when D+D fuse.
9. The emitted energy of the $^{4}$H is sufficient to produce transmutation and hot fusion products.
10. Fractofusion may be a consequence of a brief cold fusion reaction.
11. Very energetic electron beams are emitted that generate photon beams.
12. The process creates magnetic fields and would be affected by an applied magnetic field.
13. The process requires gaps having a critical size.
14. Use of normal H will produce a larger He/energy ratio compared to the use of pure D.
15. A practical generator design requires the ability to increase the temperature, apply a current through the material, apply a magnetic field, and form the NAE by nano machining.

**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 $12 billion gamble, Science 214 (2006) 238.
[3] J.R. Huizenga, Cold fusion: The scientific fiasco of the century, second ed., Oxford University Press, New York, 1993.
[4] S.B. Krivit, Fusion Fiasco, Explorations in Nuclear Research, Vol. 2-The behind-the-scenes story of the 1989-1990 fusion fiasco, Pacific Oaks Press, San Rafael, CA, 2016.
[5] E.K. Storms, The science of low energy nuclear reaction, World Scientific, Singapore, 2007.
[6] D. Nagel, Hot and cold fusion for energy generation, J. Cond. Matter Nucl. Sci. 4 (2011) 1-16.
[7] E.N. Tsyganov, V.M. Golovatyuk, S.P. Lobastov, M.D. Bavizhev, S.B. Dabagov, Registration of energy discharge in D + D =4He* reaction in conducting crystals (simulation of experiment), Nucl. Instr. and Meth. in Phys. Res. B 309 (2013) 95-104.
[8] E.K. Storms, The Material Science Aspects of Low Energy Fusion, in: www.LENR.org (Ed), 2023.
[9] E.K. Storms, The Nature of Cold Fusion (Cold Fusion Made Simple), Solid State Energy Summit, ICCF24, www.LENR.org, Mountain View, CA, 2022.
[10] E.K. Storms, B. Scanlan, Radiation produced by glow discharge in deuterium, in: J. Rothwell, P. Mobberley (Eds), 8th International Workshop on Anomalies in Hydrogen / Deuterium Loaded Metals. 2007., http://www.iscmns.org/catania07/index.htm. The International Society for Condensed Matter Science, Catania, Sicily, 2007, pp. 297-305.
[11] E.K. Storms, The explanation of low energy nuclear reaction, Infinite Energy Press, Concord, NH, 2014.
[12] E.K. Storms, The status of cold fusion (2010), Naturwissenschaften 97 (2010) 861.
[13] S. Pons, M. Fleischmann, Heat after death, Trans. Fusion Technol. 26 (1994) 87-95.
[14] S. Pons, M. Fleischmann, Etalonnage du systeme Pd-$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).
[15] 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.
[16] E. Storms, Anomalous Energy Produced by PdD, J. Cond. Matter. Nucl. Sci. 20 (2016) 81-99.
[17] E. Storms, The Nature of the D+D Fusion Reaction in Palladium and Nickel, JCMNS 36 (2022) 377-94.
[18] 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.
[19] E.K. Storms, Measurements of excess heat from a Pons-Fleischmann-type electrolytic cell using palladium sheet, Fusion Technol. 23 (1993) 230.
[20] E.K. Storms, Some characteristics of heat production using the "cold fusion" effect, Trans. Fusion Technol. 26 (1994) 96.

[21] 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.
[22] 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.
[23] 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.
[24] 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.
[25] D. Letts, D. Cravens, Laser stimulation of deuterated palladium, Infinite Energy 9 (2003) 10.
[26] 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.
[27] 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.
[28] 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.
[29] M.J. Guffey, Y. Tang, P.J. King, Attempted Replication of Excess Heat in the Letts Dual-laser Experiment, JCMNS 20 (2016) 1-28.
[30] 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.
[31] P.L. Hagelstein, D. Letts, Analysis of some experimental data from the two-laser experiment, J. Cond. Matter Nucl. Sci. 3 (2010) 77-92.
[32] M.R. Swartz, P.L. Hagelstein, Increased PdD anti-Stokes Peaks are Correlated with Excess Heat Mode, JCMNS 24 (2017) 130-45.
[33] M. Swartz, Active LANR Systems Emit a 327.37 MHz Maser Line, J. Cond. Mater. Nucl. Sci. 33 (2020) 81-110.
[34] 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.
[35] A. Coehn, Nachweis Von Protonen in Metallen, Z. Elektrochem. 35 (1929) 676.
[36] F. Tanzella, R. George, R.E. Godes, Nanosecond Pulse Stimulation in the Ni–H2 System, J. Cond. Matter. Nucl. Sci. 29 (2019) 202-10.

[37] R. Godes, Quantum Fusion Hypothesis, ICCF-14, Washington, DC., 2008.
[38] 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.
[39] 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.
[40] 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.
[41] 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.
[42] 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.
[43] F.E. Gordon, H.J. Whitehouse, Lattice Energy Converter, JCMNS 35 (2022) 30-48.
[44] 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.
[45] G.C. Abell, L.K. Matson, R.H. Steinmeyer, R.C. Bowman Jr., B.M. Oliver, Helium release from aged palladium tritide, Phys. Rev. B: Mater. Phys. 41 (1990) 1220.
[46] 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.
[47] L. Case, Coprioductioin of energy and helium from D2, WO 97/43768, USA, 1997.
[48] A.B. Karabut, Y.R. Kucherov, I.B. Savvatimova, Nuclear product ratio for glow discharge in deuterium, Phys. Lett. A 170 (1992) 265-72.
[49] 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.
[50] P.A. Mosier-Boss, F.E. Gordon, L.P. Forslery, D. Zhou, Detection of high energy particles using CR-39 detectors part 1: Results of microscopic examination, scanning, and LET analysis, International J. Hydrogen Energy 42 (2017) 416-28.
[51] S. Szpak, J. Dea, Evidence for the induction of nuclear activity in polarized Pd/H–$H_2O$ system, J. Cond. Matter Nucl. Sci. 9 (2012) 21-9.
[52] P.A. Mosier-Boss, J. Dea, F. Gordon, L. Forsley, M. Miles, Review of twenty years of LENR research using Pd/D co-deposition, J. Cond. Matter Nucl. Sci. 4 (2011) 173-87.
[53] 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.
[54] 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.
[55] F.E. Gordon, H.J. Whitehouse, Lattice Energy Converter II: Iron Hydrogen Host Material, JCMNS 36 (2022) 1-24.
[56] S. Szpak, P.A. Mosier-Boss, J.J. Smith, Deuterium uptake during Pd-D codeposition, J. Electroanal. Chem. 379 (1994) 121.
[57] E.K. Storms, B. Scanlan, Nature of Energetic Radiation Emitted from a Metal Exposed to $H_2$, J. Cond. Matter Nucl. Sci. 11 (2013) 142-56.
[58] 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.
[59] 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.
[60] Y. Fukai, Formation of superabundant vacancies in metal hydrides at high temperatures, J. Alloys and Compounds 231 (1995) 35-40.
[61] 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.
[62] 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.
[63] 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.
[64] 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.
[65] K. Czerski, New evidence of the cold nuclear fusion – accelerator experiments at very low energies, New Advances on the Fleischmann-Pons Effect, European Parliament, Brussels, 2013.
[66] 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.
[67] G. Preparata, Fractofusion revisited, in: S. Jones, F. Scaramuzzi, D. Worledge (Eds), Anomalous Nuclear Effects in Deuterium/Solid Systems, "AIP Conference Proceedings 228", American Institute of Physics, New York, Brigham Young Univ., Provo, UT, 1990, pp. 840.

[68] L.H. Bagnulo, Crack-fusion: A plausible explanation of cold fusion, in: T. Bressani, E. Del Giudice, G. Preparata (Eds), Second Annual Conference on Cold Fusion, "The Science of Cold Fusion", Societa Italiana di Fisica, Bologna, Italy, Como, Italy, 1991, pp. 267.
[69] K. Yasui, Fractofusion mechanism, Fusion Technol. 22 (1992) 400.
[70] 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.
[71] G.M. Ter-Akopian, Y.T. Oganessian, D.D. Bogdanov, A.S. Fomichev, M.S. Golovkov, A.M. Rodin, S.I. Sidorchuk, R.S. Slepnev, S.V. Stepantsov, R. Wolski, V.A. Gorshkov, M.L. Chelnokov, M.G. Itkis, E.M. Kozulin, A.A. Bogatchev, N.A. Kondratiev, I.V. Korzyukov, A.A. Yukhimchuk, V.V. Perevozchikov, Y.I. Vinogradov, S.K. Grishechkin, A.M. Demin, S.V. Zlatoustovskiy, A.V. Kuryakin, S.V. Fil'Chagin, R.I. Ilkaev, F. Hanappe, T. Materna, L. Stuttge, A.H. Ninane, A.A. Korsheninnikov, E.Y. Nikolski, I. Tanihata, P. Roussel-Chomaz, W. Mittig, N. Alamanos, V. Lapoux, E.C. Pollacco, L. Nalpas, Hydrogen-4 and Hydrogen-5 from t+t and t+d transfer reactions studied with a 57.5-MeV triton beam NUCLEAR PHYSICS IN THE 21st CENTURY, AIP Conference Proceedings, Volume 610, pp. 920-924 (2002). 2002.
[72] R.E. Godes, The quantum fusion hypothesis, Infinite Energy 14 (2008) 15-23.
[73] M.R. Swartz, G. Verner, Bremsstrahlung in hot and cold fusion, J. New Energy 3 (1999) 90-101.
[74] A.B. Karabut, Excess heat power, nuclear products and X-ray emission in relation to the high current glow discharge experimental parameters, 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. 151.
[75] A.B. Karabut, Characteristics of X-ray emission from solid-state cathode medium in electric discharge systems, in: Y. Bazhutov (Ed) 13th International Conference on Condensed Matter Nuclear Science, Tsiolkovsky Moscow Technical University, Dagomys, city of Sochi, 2007, pp. 73.
[76] A.B. Karabut, E.A. Karabut, P.L. Hagelstein, Spectral and temporal characteristics of X-ray emission from metal electrodes in a high-current glow discharge, J. Cond. Matter Nucl. Sci. 6 (2012) 217-40.
[77] M.R. Staker, How to achieve the Fleischmann-Pons heat effect, J. Hydrogen Energy www.sciencedirect.com (2022).
[78] R. Mills, The grand unified theory of classical quantum mechanics, Cadmus Professional Communications, Ephrata, PA, 2006.
[79] A. Rathke, A critical analysis of the hydrino model, New J. Phys 7 (2005) 127.
[80] A. Meulenberg Jr., From the naught orbit to the $^{4}$He excited state, J. Cond. Matter Nucl. Sci. 10 (2013) 15-29.
[81] K. Shoulders, S. Shoulders, Observations on the Role of Charge Clusters in Nuclear Cluster Reactions, J. New Energy 1 (1996) 111-21.
[82] H. Fox, S.X. Jin, Low-energy nuclear reactions and high-density charge clusters, J. New Energy 3 (1998) 56.
[83] S.-X. Jin, H. Fox, Characteristics of high-density charge clusters: A theoretical model, J. New Energy 1 (1996) 5-20.

[84] 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.
[85] G.K. Hubler, A Possible Heuristic Explanation of Exotic Vacuum Objects (EVO's, Charge Clusters), JCMNS 36 (2022) 30-7.
[86] 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.
[87] 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.
[88] 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.
[89] E.H. Lewis, Tracks of ball lightning in apparatus?, J. Cond. Matter Nucl. Sci. 2 (2009) 13.
[90] J. Song-Sheng, L. Jing-Huai, W. Jian-Qing, H. Ming, S.-Y. W., Z. Hong-Tao, Y. Shun-He, Z. Yong-Gang, Measurement of anomalous nuclear reaction in deuterium-loaded meta, Chinese Phys. B 18 (2009) 1428.
[91] S. Jiang, J. Liu, M. Hea, A possible in-situ $^{3}$H and $^{3}$He source in Earth's interior: an alternative explanation of origin of $^{3}$He in deep Earth, Naturwissenschaften 97 (2010) 655-62.
[92] 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.