

Research Article

The Nature of the D+D Fusion Reaction in Palladium and Nickel

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Abstract

The LENR reaction can be made to occur in Pd and Ni having different physical forms. The behaviors of solid Pd, sintered Pd powder, and sintered Ni powder are discussed in this paper. The required deuterium ions can be made available to the LENR process by using electrolysis or exposure to D₂ gas. Initiation of the nuclear reaction sometimes requires the creation of a large D/Pd ratio, but not always. In many cases, very little deuterium is required to produce detectable heating power, which is the thermal energy expressed in watts. In every case, the amount of power is not affected by the D/Pd ratio after the nuclear process starts. Also, increased temperature causes the amount of power to increase exponentially, with the activation energy being related to the source of deuterons available to the nuclear process. The reaction involving deuterium emits part of the nuclear energy as energetic ions having the characteristics of a hydrogen isotope, but not helium [1]. Very little photon radiation is detected outside the walls of the container in which the source is located. The behavior is consistent with the nuclear active environment (NAE) being in physical gaps having a critical width located outside the crystal structure, not in vacancies located within the lattice structure. Successful production of LENR involves the formation of these sites in high concentration and with reliability. This paper describes an effort to meet this challenge.

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1. Introduction

Effective study of LENR (Low Energy Nuclear Reaction) [2] requires the application of a model, theory, or perhaps even something as simple as an expectation. The choice of which idea to use is made difficult by so many being suggested, perhaps too many. I summarized and evaluated many of the published suggestions, including my own, in my book [3]. This paper will focus on the model I first suggested in 2003 and have expanded over the years [4], [5].

This model has two parts. One applies to the physical-chemical environment required for the nuclear process to occur and the second part applies to the nuclear reaction itself. I will address only the first part in this paper.

The model proposes that a particular condition must form in the material consisting of gaps having a critical width. This condition is called the NAE (Nuclear Active Environment). The hydrogen isotopes are assumed to accumulate within these sites by a conventional chemical process. For reasons still unknown, the assembly of hydrogen nuclei can then experience collective fusion with the production of energy and nuclear products including helium and tritium.

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Radiation is also produced, with most of it being unable to pass through the walls of the surrounding apparatus. The greater the number of the gaps that are populated by a hydrogen isotope, the larger is the resulting thermal power. In contrast, the complete absence of the critical gaps prevents LENR from occurring regardless of how the material is treated. Therefore, the concentration of suitable gaps, as determined by the nature of the material, is one of the critical variables. The other critical variable is temperature. Both are described in this paper.

It is important to realize that other mechanisms, besides LENR, can be caused to operate when extra energy is applied in the form of energetic deuterons [6]–[9] or photons [10]. These reactions are related to what is called hot fusion. Consequently, the behavior must not be confused with the mechanism causing LENR, because entirely different nuclear products are produced.

The necessary gaps can be created in many different ways. The method described here involves the use of powder to which physical pressure is applied with sufficient force to increase the contact between the particles. This method has been used by other studies [11]–[13] but without the creation of gaps as the intended goal or without suitable methods of activation. As result, perhaps the treatments were not as effective as they might have been if the critical variables had been correctly identified. In the case of the method used here, extra energy is produced without fail after proper pre-treatment of the material based on consideration of the variables described here.

Based on my model, force-pressing a powder into a low-density structure would be expected to create a useful material because a large collection of gaps would form, some with a suitable dimension. In addition, a large fraction of the material would be directly accessible by the gas used to activate the sites. The need to achieve a large D/Pd ratio for activation, as found when solid Pd is used [14]–[16], would not be expected and was not found to be necessary.

The first step is to create a sufficient number of active gaps to produce enough power to make studies possible. That goal has been achieved in this study. The next step is to learn how to increase the number of active sites in order to increase the amount of excess power. That effort is underway.

2. Experimental

The information presented here comes from measurement of excess thermal power production using a sensitive Seebeck calorimeter [17]. The calorimeter consists of a water-cooled box held at a constant temperature of 10°C. The walls of the box are lined with 54 thermoelectric converters (Custom Thermoelectric, 12711-5P31-12CW) connected in series. The converters generate a voltage that is proportional to the average amount of thermal power being conducted through their thickness, which generates a Seebeck voltage proportional to the heat energy being lost from anywhere in the box. The relationship between the voltage and the heat energy is obtained from a suitable calibration.

Different cell designs can be placed in the box to study electrolysis, gas loading, or gas discharge without the need for modification. Magnetic fields and/or laser light can be easily applied and radiation detectors (Geiger-Mueller (GM) and other types) can be placed in the box near the sample. The calorimeter was tested for accuracy by measuring the enthalpy of fusion of tin at 212°C and the enthalpy of formation of PdH_x [18] as a function of H content. Both measurements agree with the accepted values.

This work used either an electrolytic cell containing an electrolyte consisting of D₂O plus LiOD or a cell in which the sample is exposed to fixed amount of low-pressure D₂ or H₂ gas. The complete history of the chemical reaction in the cell, including all energy entering and leaving the cell, is recorded electronically every minute using LabView.

The cells are heated by resistance wire wrapped around their outside, with the electrolytic cell reaching 90°C by applying 26 watts and the gas cell reaching 300°C by using 13 watts. The gas cell reaches a higher temperature because it is not limited by the boiling point of D₂O and it is better insulated than the electrolytic cell. Temperature is measured using several RTDs (Pt resistance temperature detector) to an accuracy of ±1°C. The temperature is not used to measure the thermal energy and the measurements made by the calorimeter are independent of the sample temperature.

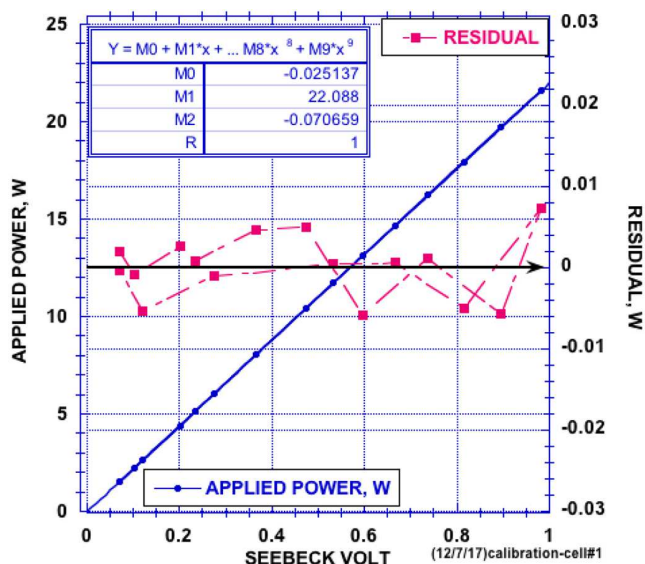


Figure 1. Typical calibration showing the relationship between Seebeck voltage and applied power. The points are taken first by increasing and then by decreasing the temperature in similar steps. A delay of 90 minutes between each measurement is used to allow the calorimeter to come to a constant temperature. The residual is the difference between the value of each point and the value obtained using the fitted equation. This value shows the amount of random variation in each measurement. The Standard Deviation of all the residual values is near ± 0.005 W.

The calorimeter is calibrated frequently by applying power to the heating wire surrounding the cell being used without a sample present. A typical calibration is shown in Fig. 1. Each cell type is calibrated separately over the full range of power used to achieve the highest temperature. Excess power is identified when P in the following equation has a positive value:

$$P = (M0) + (M1)*S + (M2)*S^2 - AP$$
 where the constants $M0$, $M1$, and $M2$ are listed in Fig. 1, S is the measured Seebeck voltage, P is the power measured by the calorimeter, and AP is the electrical power applied to all items in the box, including a fan.

The open calorimeter box containing an electrolytic cell is shown in Fig. 2. The balance with the oil container shown on the right is used to measure the amount of orphaned oxygen released when D reacts with Pd in the electrolytic cell.

The open Pyrex electrolytic cell is shown in Fig. 3. Both the anode and reference electrode are Pt and the recombiner is a commercial fuel-cell catalyst made by depositing nano- Pd on carbon cloth (FuelCellsEtc, HLGDE-W1S1010). The electrolyte is 30 ml of D_2O to which about 0.1 g of Li metal was reacted. All gas entering or leaving the cell is measured as a weight change of displaced oil.

The assembly used to measure the temperature of the recombiner is shown in Fig. 4. All gas leaving the cell must pass next to the catalyst where the temperature increase caused by the $D_2 + O_2$ reaction can be measured by a nearby RTD. Any remaining O_2 (orphaned oxygen) is carried through a small plastic tube to the oil reservoir shown in Fig. 2.

Figure 5 shows the Seebeck calorimeter containing the gas-loading cell. This gas-cell has a volume of 17 ml. Two RTDs, one on the inside and one on the outside of the Pyrex wall are used to measure the temperature every minute. Resistance wire wrapped on the outside is used to heat the cell up to near $300^\circ C$. The cell is sealed using spring-loaded screws to hold the glass against a rubber seal. The cell is evacuated to a pressure of less than 5×10^{-6} torr before

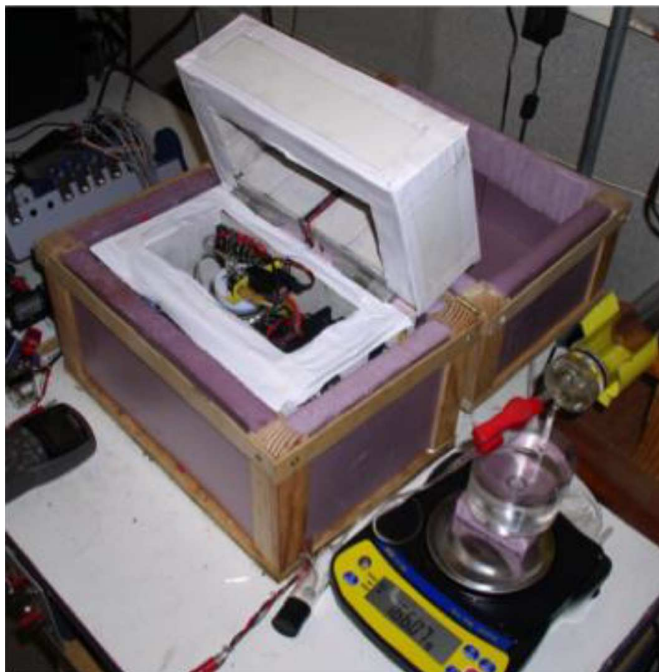


Figure 2. The open Seebeck calorimeter containing the electrolytic cell, with the apparatus for measuring orphaned oxygen on the right. The amount of released O_2 is measured using the weight of displaced mineral oil from a reservoir.

being loaded with D_2 at a known pressure, generally between 200 and 700 torr. Because a small volume with a small initial pressure is used, the amount of D is limited to less than 0.0004 mol. The temperature and prevailing equilibrium pressure determine the amount of this D that reacts with the Pd. When fully reacted, the typical D/Pd ratio would be less than 0.02. Consequently, studies involving gas loading involve only the alpha phase in which the D atoms occupy a few random interstitial positions between the Pd atoms in the face-centered-cubic (fcc) structure.

When electrolysis is used, the D/Pd ratio is measured in three different ways. Examples are compared using unpublished data from a previous study in Fig. 6.

The orphaned oxygen method (OO) measures the amount of oxygen left behind when the D_2O reacts with the Pd, as described above.

The temperature of the catalyst (RT) used to recombine any excess D_2 and O_2 allows the D/Pd ratio to be calculated as follows:

The number of moles of deuterium being made available for reaction with Pd by the electrolytic current can be determined using the equation:

$$\text{Moles H or D} = M = \text{seconds} * \text{current} / 98485. \quad (1)$$

Because the time interval is 60 seconds and the current is 0.101 A for this study, the total number of moles of deuterium generated in the cell during the measurement interval is:

$$M_D = 60 * 0.101 / 98485 = 6.15 \times 10^{-5} \text{ moles/min} \quad (2)$$

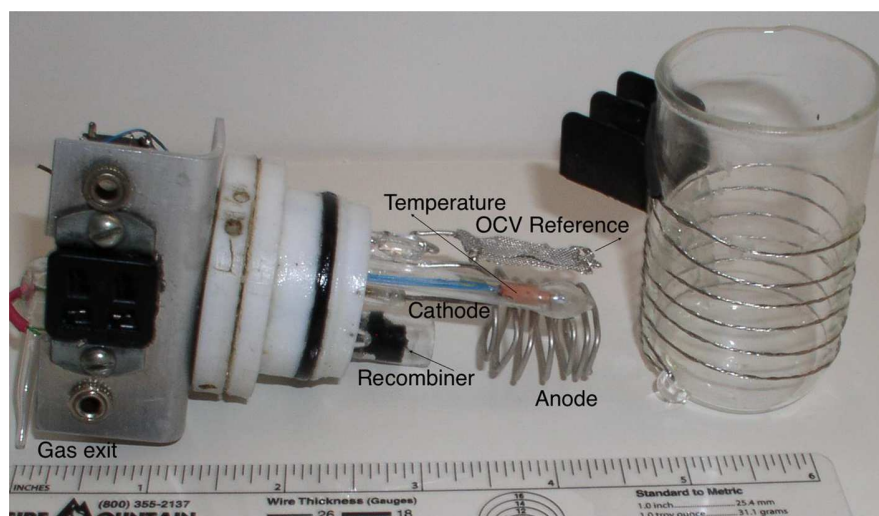


Figure 3. Components of the Pyrex electrolytic cell. The top is Teflon. All glass exposed to the electrolyte is Pyrex and all exposed metal is platinum, except the cathode, which is attached by a plastic clamp that allows rapid removal.



Figure 4. Assembly used to measure catalyst temperature after being removed from the cell shown in Fig. 3. Gas containing a mixture of D_2 and O_2 will form D_2O at the catalyst, seen as the black region in the photograph. The resulting temperature increase is detected by an RTD contained in a sealed Pyrex tube located next to the catalyst. Excess O_2 can leave the cell through a gap between the inner and outer tubes.

Deuterium that reacts with the Pd is not available to combine with O_2 gas at the recombiner, hence does not contribute to an increase in recombiner temperature. Therefore, the increase in temperature can be used to determine how much D has reacted with the metal and the rate of this reaction.

Finally, in a few tests, the sample was weighed at the end of the loading process to determine the final amount of D in the Pd as follows:

Because D is lost from the Pd when the electrolytic current is stopped, a plot of deuterium content vs square root of time is extrapolated to zero time, as shown in Fig. 7, to determine the D content at the time the current was stopped. This method can only be applied to solid Pd because the porous material retains an unknown amount of fluid after it is removed from the electrolyte.

This loss of deuterium also occurs when the electrolytic current is stopped while the sample is in the electrolytic cell, as is occasionally done to determine the effect of the D/Pd ratio on thermal power production. Figure 8 shows how the D/Pd changes over time, as the final D/Pd approaches the equilibrium value created by the activity of D_2 present

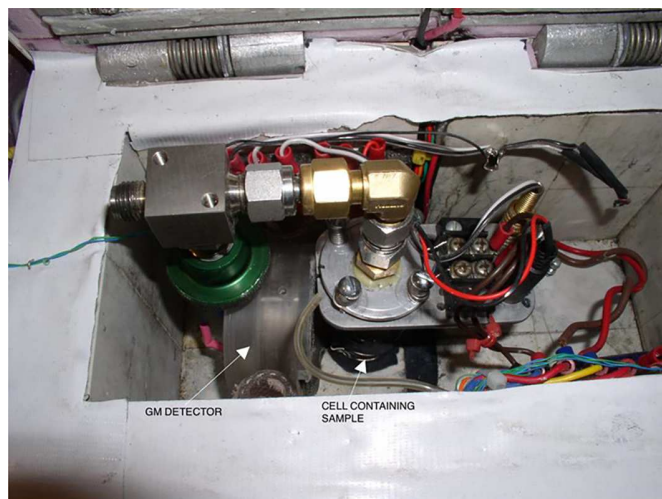


Figure 5. Seebeck calorimeter containing the gas-loading cell used to react the metal with D_2 or H_2 gas. A Geiger-Muller detector is shown next to the cell containing the sample. No radiation has been detected. The fan in the top of the box is not shown.

in the cell. Surprisingly, neither a large number of flaws nor the cracks in the surface of the pressed material seem to have much influence on this behavior.

When gas loading is used, the maximum D/Pd ratio at room temperature is calculated from the known volume of the cell combined with the known pressure of D_2 added with the sample, assuming all D had reacted. The amount of D combined with the Pd decreases as the sample is heated. Consequently, this method involves a change in the amount of D in the Pd as the temperature is changed. The initial amount of D is kept small because if enough D_2 were added to cause the beta phase to form, the pressure could become much too large for the cell to contain. Therefore, an amount of D_2 is used such that the pressure does not increase above 2 atm at 300°C . Therefore, the beta phase is not present during these studies.

Figure 9 shows the nature of the reaction when oxidized Pd reacts with a supply of D_2 gas sufficient to form some beta phase. The initial reaction is fast enough to heat the sample. The D/Pd ratio is calculated from the pressure change of a fixed volume of gas exterior to the cell. This behavior demonstrates just how reactive the Pd sample is to D_2 gas.

3. Results

3.1. Sample Preparation

The samples were prepared by pressing the powders in a steel die to form a disk shape about 12 mm in diameter and about 2 mm thick. This disk was then subjected to various treatments including heating in a vacuum at $900\text{--}1000^\circ\text{C}$ and/or heating in air at various temperatures and times. The amount of physical pressure used to compact the powder was not explored but is expected to affect the amount of generated power. The formation of an oxide layer and the addition of various inert materials in the form of a fine powder are also found to affect success. Even though the conditions were not optimized, active samples could be made with reliability. Although many variables and treatments were explored during this study, this paper is focused only on a few behaviors produced by a few samples to show a few examples of typical behavior.

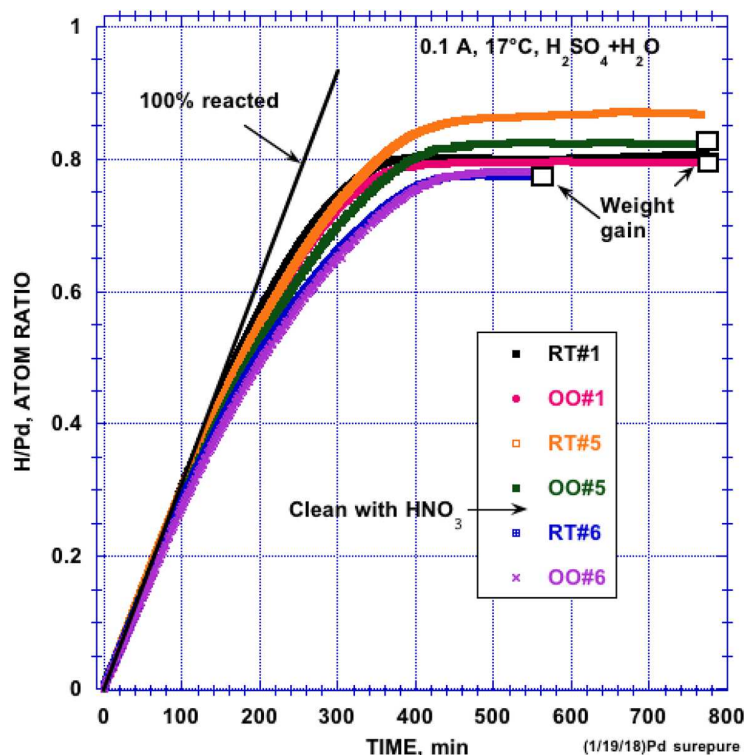


Figure 6. Comparison between the D/Pd ratio measured by orphaned oxygen (OO), catalyst temperature (RT), and weight gain after loading. Agreement between the different methods gives confidence in the accuracy of the measurement.

The pressed material has a surface structure shown in Fig. 10. The amount of free volume is variable among the samples but is between 28% and 50%. The samples of Pd generally weighed about 1.5 g. Their dimensions were measured and used to determine the free volume. The dimensions changed as a result of loading and heating in ways that revealed important information about the structure of the material. These behaviors will be discussed in a later paper.

A sample of pressed Pd powder (1.7 g) containing an additive was reacted at 1000°C in a vacuum for 19 hr. Afterward, it showed the loading behavior plotted in Fig. 11 when reacted with D using electrolysis. Despite the many ways the D could escape, this sample loaded to D/Pd = 0.9. Nevertheless, no excess power was produced when the sample was heated to 91°C in the electrolytic cell.

This sample was then heated in air to 800°C and cooled in the furnace, thereby causing a weight increase of 0.01442g consisting of oxygen as PdO that was formed throughout the open structure. The sample was again reacted with D. This time the apparent D/Pd increased to 0.95 as a result of the reduction of the extra PdO. Excess thermal power was made with and without electrolytic current being applied to the sample when heated to 91°C. The sample was then removed from the electrolytic cell and placed in the gas cell with about one atm of D₂. The cell was heated in steps to 215°C. Once again, excess power was made with the amount being consistent with the behavior in the electrolytic cell. The power produced with and without electrolytic current is compared in Fig. 12 to the power made when the sample is heated in D₂ gas. This agreement is not an artifact because 26 W of applied power was used to

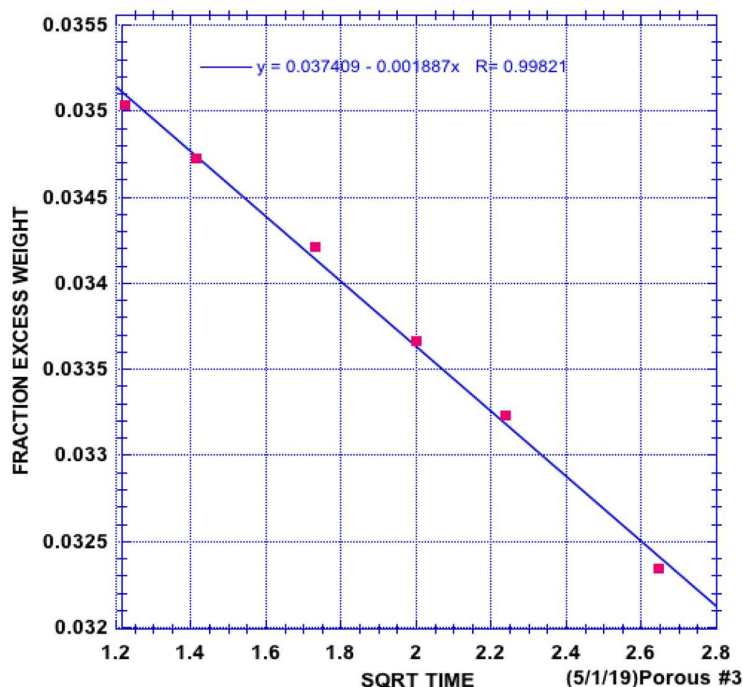


Figure 7. Typical weight loss of D_2 plotted as the square root of time (SQRT) when Pd is allowed to lose D_2 in air. The straight line is extrapolated to zero time to determine the D/Pd ratio at the time the sample was removed from the calorimeter.

produce a temperature of 93°C in the electrolytic cell while this same temperature was reached by applying only 7 W to the gas cell. In both cases, the applied power is within the range of the calibration used at the time. Also, this type of calorimeter is not sensitive to the temperatures in the cells.

The pure Pd powder does not produce LENR immediately after pressing or after sintering in a vacuum. Heating in the presence of O_2 or H_2O gas is required to activate the material. Because a large surface is accessible to the oxidizing gas, an amount of reacted oxygen is sufficient to cause a detectable weight increase of several milligrams. The amount of power did not correlate with the amount of oxygen reacted, although too much or too little oxide formation would prevent the LENR reaction.

Somewhat different methods were used to activate nickel powder. This treatment will be described elsewhere.

3.2. Effect of Temperature

Temperature is one of the more important variables affecting the LENR reaction. Increased temperature can make an apparently dead material appear alive when the amount of power finally exceeds the sensitivity limit of the calorimeter. Indeed, I suspect people would have had much greater success in detecting LENR if they had simply increased the temperature. In addition, the activation energy calculated using temperature reveals important information about the mechanism.

Dong *et al.* [20] (Figure 13) provided a summary of published values for the relationship between Log EP vs $1/T$, including the result of their own measurements. They used the resulting straight lines and slopes to support a resonant

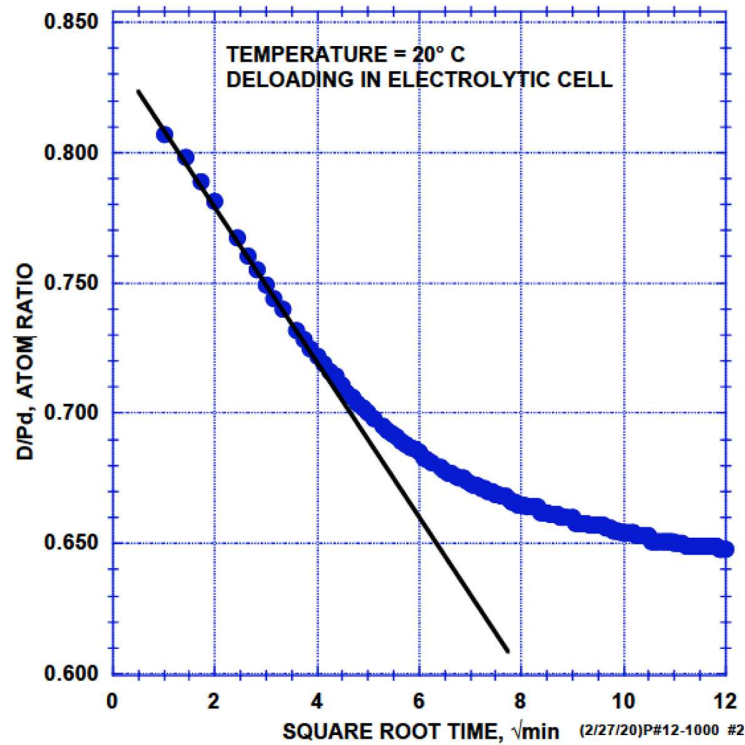


Figure 8. Example of deuterium loss when the electrolytic current is stopped at 20° C while a sintered sample is in the electrolyte. The loss rate increases when the temperature is increased. The D/Pd ratio is calculated using the orphaned oxygen method.

surface capture model [21]. In addition, they propose that the diffusion of D through various materials in the material is related to the effect of temperature.

Figure 14 compares several of my previous studies using solid Pd to the powdered Pd described in this paper. The data labeled B, which is a sample using powdered Pd, was heated in the electrolytic cell, first with 0.1 A applied to produce a measured D/Pd ratio of 0.85. Then current was turned off while the cell was again heated. At the end of the first run the D/Pd ratio has decreased from 0.85 to 0.56. At the end of the second run, the ratio had decreased to 0.51 and then to 0.46 at the end of the third run. In each case, the values all showed the same behavior. In other words, the D/Pd ratio had no effect on the amount of power. Also notice that a break in slope occurs, suggesting a change in the mechanism.

Another powdered sample shown by the red points labeled A produced less power but showed the same effect of temperature.

The points shown in green and labeled C were produced by a solid piece of Pd published by Storms [19], [22] to which 0.1 A was applied. Notice it has the same slope as the powder samples when studied in the electrolytic cell.

A very early study of solid Pd (1994) [23], labeled D, was unknowingly made in the transition region, which caused the slope to fall between the two effects. This demonstrates the importance of making measurements over a wide temperature range.

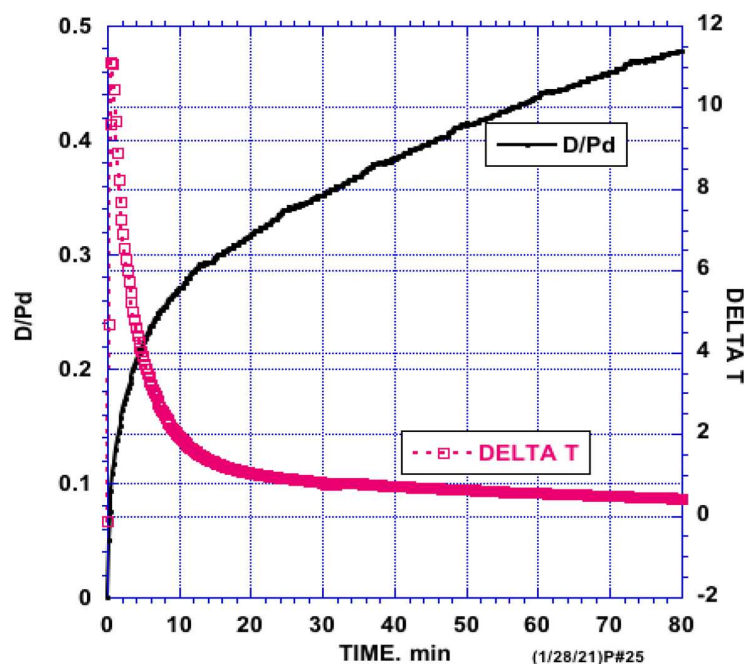


Figure 9. Change in sample temperature (degrees Celsius) compared to the resulting D/Pd ratio as 1.5 g of oxidized Pd reacts with D_2 gas initially at room temperature. The delta T is the temperature difference between the inside and outside of the cell. Most of the initial temperature increase results from the reaction of PdO with D_2 .

The relationship between $\log EP$ and $1/T$ is shown in Fig. 15 using the values plotted in Fig 12 for a powdered sample. A similar effect of temperature is revealed in the low temperature region when electrolysis and the gas loading are used. In this case, the transition temperature is too high to reveal the behavior of the high temperature region when electrolysis is used. In contrast, this region can be easily identified when gas loading is used. It is important to note that the behavior in the low temperature region is the same as that caused by electrolysis.

The behavior of an activated sample of Ni powder is shown in Fig. 16. Once again, the behavior is the same as that produced by pressed Pd, but with a larger transition temperature.

4. Discussion

When pressed into a compact form, powdered Pd and powdered Ni can produce energy by LENR after suitable activation. Energy production can be initiated using electrolysis or by direct exposure to D_2 or H_2 gas. Both methods and both materials produce similar behavior, suggesting the thermal power results from the same mechanism. In both cases, the amount of energy is not influenced by the D content.

What do the observed behaviors mean in terms of the model being applied here?

The model identifies three processes that are required to operate before LENR can occur. First, sites must form into which D or H can assemble. For the sake of this discussion, only the role of D will be described. These sites are created by the proper initial treatment of the material. Next, a collection of D atoms must assemble at these sites. This process is controlled by the Gibbs energy difference between the D in the collective and where the D is located

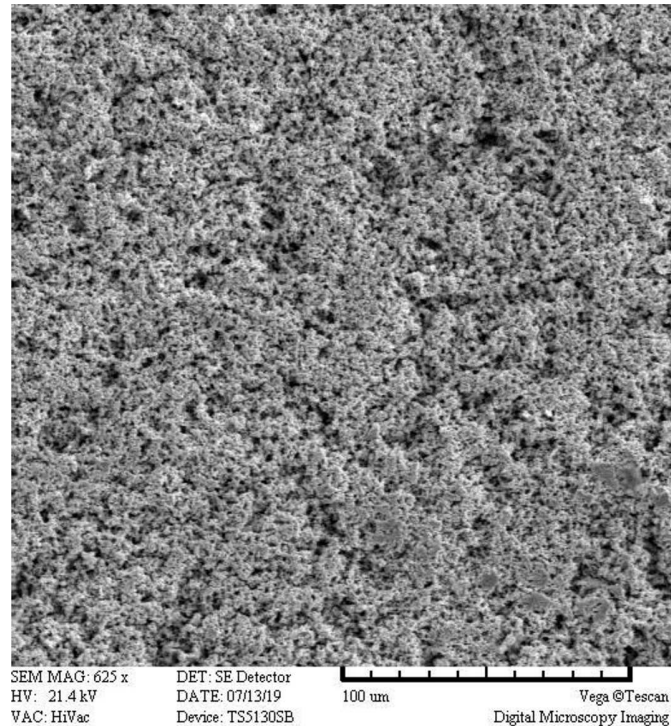


Figure 10. SEM picture of a typical pressed sample.

in the surrounding material. Both the D/Pd ratio[18], and the temperature, with temperature having the greater effect, determine the Gibbs energy. An increased number of sites would be populated as both the temperature and D/Pd ratio are increased. This process is proposed to cause the temperature effect in the low-temperature region.

After the sites have become populated and the fusion process starts, the rate of thermal power would be determined by how fast the D replaces the atoms as they are converted to He. This replacement requires transport of the atoms through the material by diffusion. This process is proposed to cause the temperature effect in the high-temperature region. An obvious transition between these two mechanisms would be expected, as seen in Figs. 14, 15, and 16, because the mechanisms affecting power production had changed.

When suitable sites are not present, the LENR effect will not happen regardless of additional treatment. The lack of reproducibility and the difficulty in producing large amounts of power are proposed to result from a variable number of suitable sites being available, with the formation of a large number being especially rare.

Therefore, the model predicts two different effects for both temperature and D content, with a transition occurring between the two mechanisms at a characteristic temperature. How does this prediction compare to the behavior described here?

Three kinds of material were studied. Solid Pd (Fig. 14) was measured using electrolysis. Pressed Pd powder (Fig. 15) was measured using both electrolysis and exposure to low-pressure D₂ gas. The pressed Ni powder (Fig. 16) was exposed only to low-pressure D₂ gas. In each case, regions were observed in which temperature had a different effect, with each showing a transition temperature between the regions. The slope of Log Power vs 1/T can

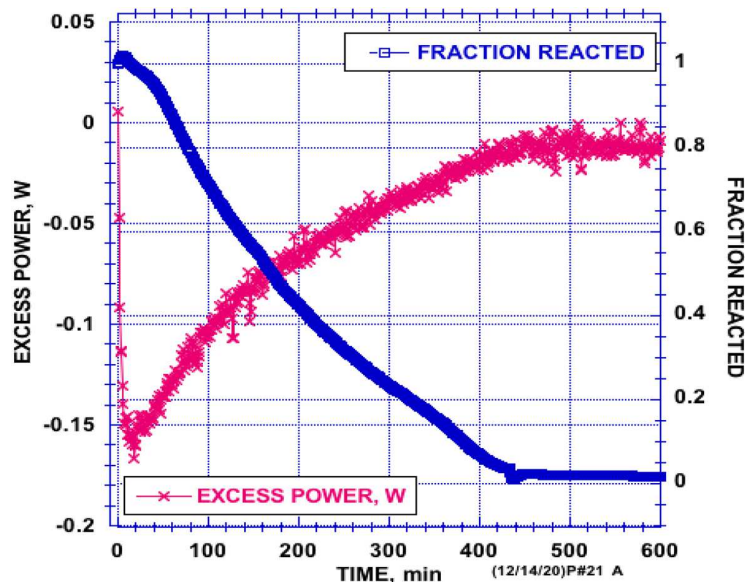


Figure 11. Relationship between the amount of excess energy and the reaction rate when 0.1 A is used to react a Pd sample with D_2O . Palladium, in both the solid and pressed-powder form, shows very similar behavior when loaded in the electrolytic cell [18], [19]. The excess energy is negative because the amount of energy used to decompose the D_2O is greater than the energy released when D_2 reacts with Pd.

Table 1. Summary of values for Activation Energy

MATERIAL	SLOPE, log/T	kJ/mol	eV/atom
Solid Pd	1526	29.22	0.303
Powder Pd	678.5	12.99	0.135
Powder Ni	676.7	12.96	0.134
Diffusion in PdD _{0.85}	1201	23.00	0.230
Diffusion in Pd [25]		25.1	0.260

be used to calculate the activation energy for the process that controls the rate of power production, with the results summarized in Table 1.

If the diffusion of D limits the rate at which power could be produced, the activation energy for diffusion should match the activation energy for power production. Both solid Pd (Fig. 14) and powdered Pd produced activation energy of 29.2 kJ/mol (0.303 eV/atom) for the higher temperature region when studied in the electrolytic cell. The activation energy for the diffusion of D in PdD_{0.85} can be calculated from data published by Majorowski and Baranowski [26] as plotted in Fig. 17. The indicated values in the figure are plotted in Fig. 18 to give activation energy of 23.0 kJ/mol. While this amount of D might be present as an average throughout the sample, the local D content would be expected to be much less as the local supply near the NAE was gradually reduced. Values for nearly pure Pd can be obtained from Lewis *et al.* [25]. They combined a large number of measurements made over a large temperature range to obtain activation energy of 25.1 kJ/mole for diffusion of H through Pd.

The agreement between the activation values suggests replacement of the D in the active sites by diffusion might be the variable limiting power production in the solid material.

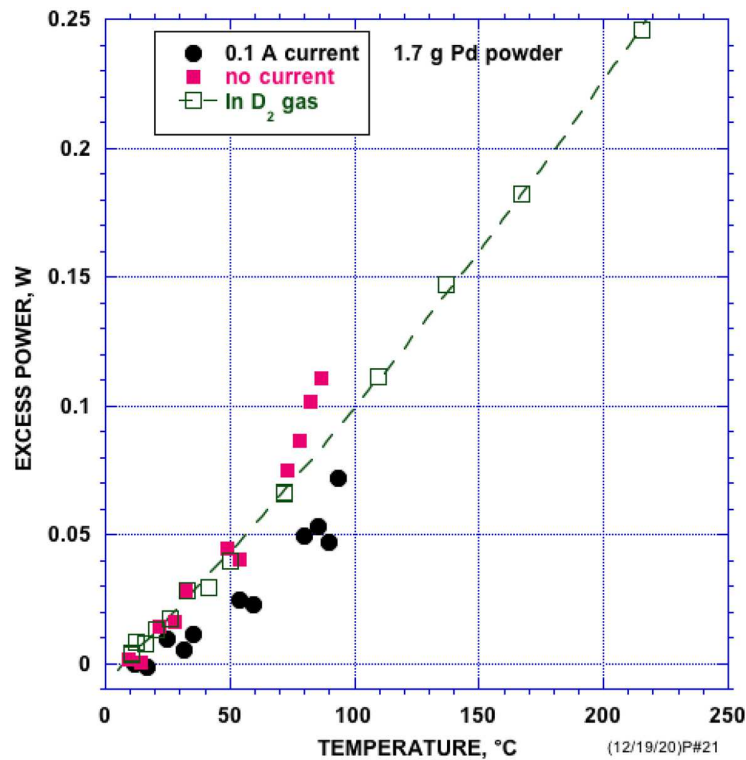


Figure 12. Comparison between power production when the measurement is done using an electrolytic cell and when the same sample of Pd is exposed to D₂ gas.

When studied in D₂ gas, the pressed powder also showed regions where the temperature had two different effects. However, the activation energy in the higher temperature region is much smaller than that found when electrolysis is used. Also, a higher transition temperature between the two mechanisms is measured.

This behavior can be explained as follows. The very open nature of the pressed material allows the active sites to be surrounded by D₂ gas. This access makes the D more easily available to the fusion process compared to the situation when electrolysis causes the supply of D to come from the surrounding solid structure. Consequently, the smaller activation energy results because the D can be obtained more directly from the gas, rather than having to diffusion through a solid structure.

Notice that the activation energies for powdered Pd and powdered Ni are almost identical when studied in D₂ gas. Perhaps this similar behavior results because both pressed materials obtain their D directly from the D₂ gas as a result of having the same physical structure.

The reported need to achieve a large D/Pd ratio in the low-temperature region [14], [27] before energy can be produced is proposed to apply only to solid Pd in which the stress produced by reaction with D is needed to form the required gaps. A large D/Pd ratio is not required to activate or increase power when the pressed powder is used because the gaps are already available.

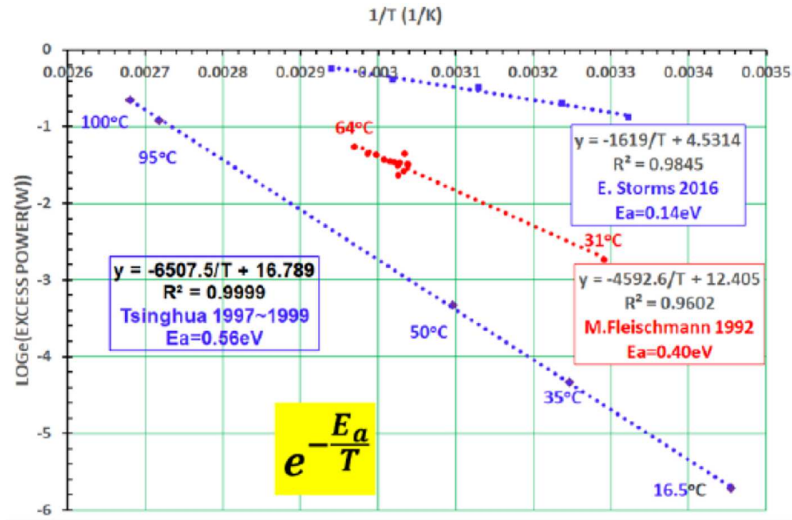


Figure 13. Summary of published values of log EP vs 1/T provided by Dong *et al.* [20].

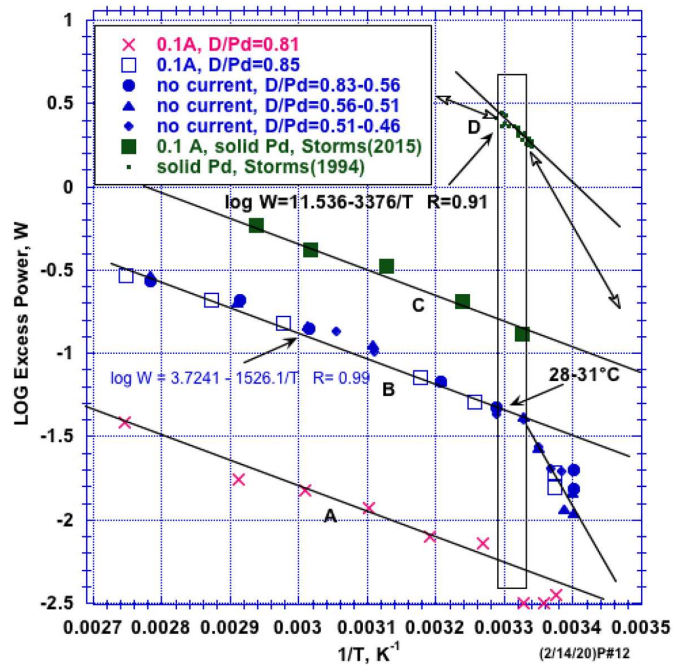


Figure 14. Comparison between the behaviors of different samples of solid and pressed Pd when heated in an electrolytic cell. The designations A, B, C, and D apply to independent measurements that are compared to show that the effect of temperature is independent of the amount of LENR power being produced and the form of the Pd. Also, the behavior is reproducible [19], [24] between measurements made years apart.

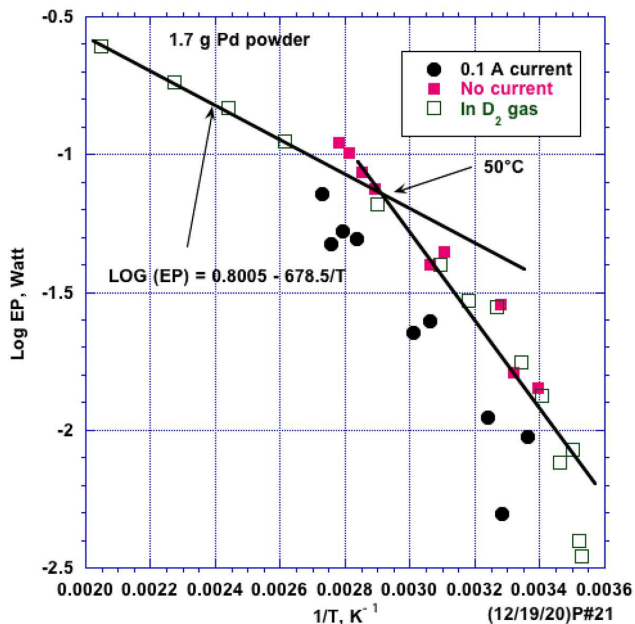


Figure 15. Relationship between log EP and 1/T for the sample of pressed Pd powder shown in Fig. 12.

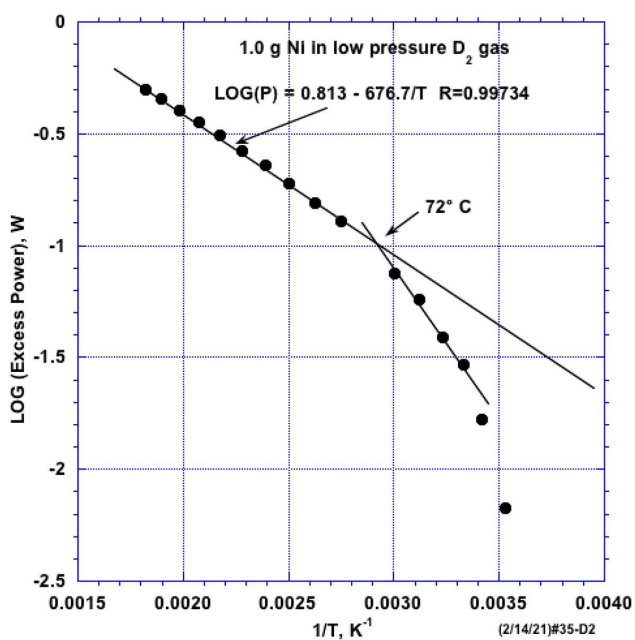


Figure 16. Relationship between Log excess power (P) and 1/T for 1 g of activated Ni powder when heated in low-pressure D₂ gas.

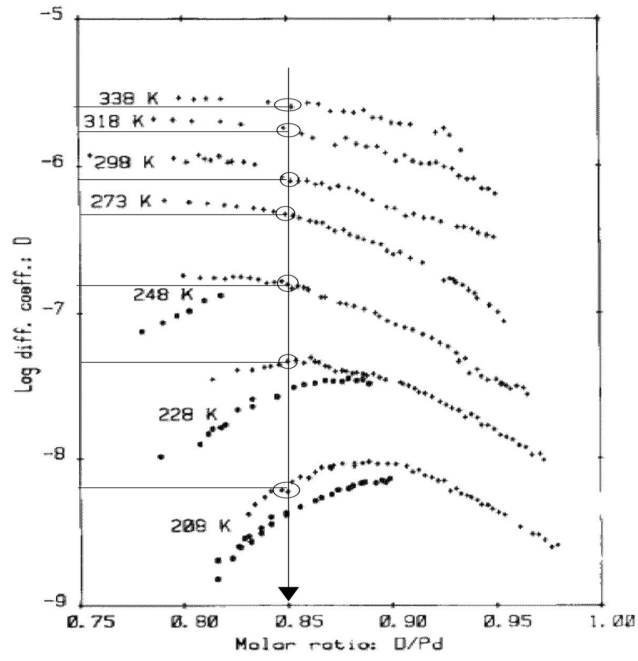


Figure 17. log Fitch diffusion constant as a function of D/Pd ratio at various temperatures. [26]

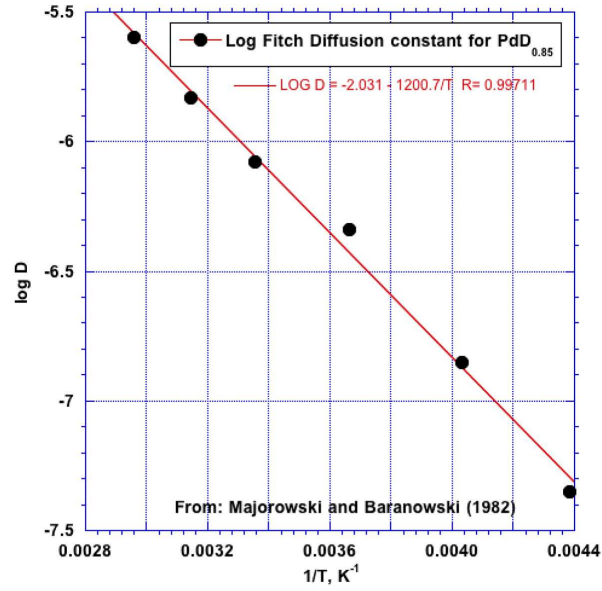


Figure 18. log Fitch diffusion constant as a function on 1/T for PdD_{0.85} (From Fig. 17 [26]).

These repeated and consistent patterns of behavior demonstrate once again that the energy claimed to result from LENR is real and not the result of prosaic mechanisms or experimental error. Also, the resulting behavior is consistent with the Storms model of LENR [28].

5. Summary

The relationship between the part of the model related to this study and the observed behavior can be summarized as follows:

1. Pd can be caused to produce LENR equally well using electrolysis or gas loading. Therefore, the conditions uniquely created by the electrolytic action are not required.
2. The temperature has two different effects, with a clear transition between the regions.
3. The LENR process is sensitive to the D/Pd ratio only in the low-temperature region. In the high-temperature region, the LENR process will function at D/Pd ratios as low as 0.01.
3. The activation energy for the LENR process in solid Pd is nearly identical to the activation energy for the diffusion of D in PdD, suggesting the amount of power produced in the high-temperature region is limited by how fast the D can repopulate the active sites by diffusion through the PdD lattice. In contrast, the activation energy of pressed Pd and Ni in D₂ gas is much smaller, indicating that the D in pressed material has much easier access to the NAE because it has a more direct contact with the source of D.
4. The LENR effect is easy to produce at low levels of energy production in pressed powders of Pd or Ni after suitable activation, with an increased temperature being required to obtain significant power.

The model used to understand the behavior can be described as follows:

1. Sites must form in which clusters of D or H can accumulate. These sites are called the nuclear active environment (NAE). These sites are proposed to be physical gaps of a critical dimension.
2. The sites fill with D or H as result of Gibbs energy being released, as is characteristic of a normal chemical process. This process is sensitive to the temperature and (D+H)/Pd ratio.
3. Once a sufficient number of atoms have accumulated at a site, they rapidly fuse by an unknown mechanism.
4. The observed power is produced by the sum of the energy produced by each site operating independently, which is determined by how fast the D and H, on average, can be replaced. This process is sensitive only to local temperature.

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